

**Technical Memorandum No 2  
Initial Screening of  
Remedial Technologies and Identification  
Of Remedial Alternatives for  
Operable Unit No 2**

**U S Department of Energy  
Rocky Flats Environmental Technology Site  
Golden, Colorado**

**Draft**

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## LIST OF ACRONYMS AND ABBREVIATIONS

Am 241	Americium 241
ARAR	Applicable or Relevant and Appropriate Requirement
AS/SVE	Air Sparging/Soil Vapor Extraction
ATTIC	Alternative Treatment Technology Information Center
C/RAO	Corrective and Remedial Action Objective
CDPHE	Colorado Department of Public Health and Environment
CERCLA	Comprehensive Environmental Response Compensation and Liability Act
CHWA	Colorado Hazardous Waste Act
CCl <sub>4</sub>	Carbon Tetrachloride
CLT	Comprehensive List of Technologies
cm	centimeters
cm/s	Centimeters per Second
CMS/FS	Corrective Measures Study/Feasibility Study
COC	Chemical of Concern
cpm	Counts per Minute
DAA	Detailed Analysis of Alternatives
DNAPL	Dense Non Aqueous Phase Liquid
DOE	U S Department of Energy
EE/CA	Engineering Evaluation/Cost Analysis
EPA	U S Environmental Protection Agency
FS	Feasibility Study
ft <sup>2</sup>	square feet
ft	foot or feet
FY	fiscal year
GRA	General Response Action
IAG	Interagency Agreement
IHSS	Individual Hazardous Substance Site
IM/IRA	Interim Measures/Interim Remedial Action
kg	kilograms
LNAPL	Light Non Aqueous Phase Liquid
LHSU	Lower Hydrostratigraphic Unit
m <sup>2</sup>	square meters
m <sup>3</sup>	cubic meters
mg	milligrams
NAPL	Non Aqueous Phase Liquid
NCP	National Contingency Plan
No	Number
NTS	Nevada Test Site
OU	Operable Unit
pCi/g	PicoCuries per Gram
pCi/L	PicoCuries per Liter
PCE	Perchloroethylene or Tetrachloroethene

PRG	Preliminary Remediation Goal
Pu 239+240	Plutonium 239+240
RCRA	Resource Conservation and Recovery Act
RFETS	Rocky Flats Environmental Technology Site
RFI/RI	RCRA Facility Investigation/Remedial Investigation
ROD	Record of Decision
RPO	Representative Process Option
RREL	Risk Reduction Environmental Laboratory
State	State of Colorado
SVE	Soil Vapor Extraction
SVOC	Semivolatile Organic Compound
SWMS	Soil Water Monitoring System
TBC	To Be Considered
TCE	Trichloroethylene
TCLP	Toxicity Characteristic Leaching Procedure
TSVE	Thermally Enhanced Soil Vapor Extraction
TSD	Treatment Storage or Disposal
UHSU	Upper Hydrostratigraphic Unit
UST	Underground Storage Tank
VISITT	Vendor Information System for Innovative Treatment Technologies
VOC	Volatile Organic Compound
WAC	Waste Acceptance Criteria

## EXECUTIVE SUMMARY

This technical memorandum addresses the development and screening of technologies and process options and presents alternatives for the remediation of surface and subsurface soils groundwater and contaminant sources associated with Operable Unit 2 (OU2) at the Rocky Flats Environmental Technology Site (RFETS). To address contaminated media OU2 has been segregated into five remediation areas consisting of the following (1) source areas for surface soil contamination (2) source areas for subsurface soil contamination (3) residual areas for surface soil contamination (4) residual areas for subsurface soil contamination and (5) contaminated groundwater.

Corrective/remedial action objectives (C/RAOs) which integrate requirements of both the Resource Conservation Recovery Act (RCRA) and Comprehensive Environmental Response Compensation and Liability Act (CERCLA) have been established for OU2. Based on these C/RAOs general response actions were developed that address the various contaminated OU2 media. Remediation targets were established in Technical Memorandum No. 1 for OU2 (DOE 1995a) based on chemical specific applicable or relevant and appropriate requirements (ARARs) and calculated risk based concentrations. A comparison of the maximum detected concentrations of chemicals of concern (COCs) against selected remediation targets was conducted. Plutonium 239+240 (Pu 239+240) was identified as the COC which exceeded remediation targets for both source and residual surface soil remediation areas. Tetrachloroethene (PCE) was identified as exceeding the selected remediation target for both source and residual remediation areas for subsurface soil. Additional characterization efforts are in progress to address other COCs in source areas for subsurface soils within OU2. These efforts will be incorporated into an engineering evaluation/cost analysis (EE/CA) which is being prepared under separate cover. Groundwater COCs which exceed the selected remediation targets include carbon tetrachloride chloroform 1,1-dichloroethene methylene chloride PCE trichloroethene vinyl chloride americium 241 (Am 241) and Pu 239+240.

Remedial technologies were screened using a two phase process. The initial phase screened technologies from the Comprehensive List of Technologies (CLT) (EG&G 1994) for technical implementability based on OU2 site specific characteristics. The second phase consisted of an evaluation of effectiveness institutional implementability and relative cost. The screening process removed technologies from further consideration that could not be implemented because of site specific factors thereby reducing the number of remedial technologies and process options for consideration in the development of remedial alternatives. Representative process options were then selected from the screened list of technologies.

Remedial alternatives were developed for each of the five remediation areas of OU2 and are summarized in the alternatives matrix presented in Table 1.1. A general description of the remedial alternatives is provided in Section 5.0. All alternatives will be evaluated in further detail in the detailed analysis of alternatives (DAA) section of the OU2 corrective measures study/feasibility study (CMS/FS).

## 1 0 Introduction

 **EG&G ROCKY FLATS**

## 1 0 INTRODUCTION

Various areas of the Rocky Flats Environmental Technology Site (RFETS) are being remediated in accordance with provisions of the 1991 Interagency Agreement (IAG) between the U S Department of Energy (DOE) the U S Environmental Protection Agency (EPA) and the State of Colorado (State) (IAG 1991) The IAG integrates closure and corrective action provisions of the Resource Conservation and Recovery Act (RCRA) and the Colorado Hazardous Waste Act (CHWA) with the hazardous substance response requirements contained in the Comprehensive Environmental Response Compensation and Liability Act (CERCLA) to ensure protection of human health and the environment

The various areas to be remediated called individual hazardous substance sites (IHSSs) are grouped into 16 operable units (OUs) As outlined in Section IX B of the IAG statement of work remedial alternatives for the corrective measures study/feasibility study (CMS/FS) for each OU are to be developed and screened This technical memorandum addresses the development and screening of technologies and process options and presents alternatives for the remediation of surface soils subsurface soils and groundwater associated with Operable Unit 2 (OU2)

This technical memorandum is intended to fulfill requirements specified in the IAG statement of work Sections IX A 2 to IX A 5 for OU2 These IAG requirements include

- Developing general response actions (GRAs) (see Section 4 0)
- Identifying areas and volumes of contaminated media (see Section 2 0)
- Identifying and screening corrective/remedial technologies (see Section 4 0) and
- Assembling the potential technologies into alternatives (see Section 5 0)

This technical memorandum contains seven sections including this introduction plus two appendices Section 2 0 of this document briefly describes site characterization information for OU2 that has been obtained through the RCRA facility investigation/remedial investigation (RFI/RI) In addition Section 2 0 provides the location and volumes of contaminated media in each remediation area Section 3 0 contains the corrective and remedial action objectives (C/RAOs) Section 4 0 presents the GRAs and results of the initial screening process for potential remedial technologies and process options Section 5 0 presents the grouping of remedial technologies into remedial alternatives for each of the remediation areas Section 6 0 identifies potential location and action specific applicable or relevant and appropriate requirements (ARARs) for each remedial alternative Figures and tables are provided in Section 7

## 2 0 Site Characteristics

2 0 Site Characteristics



## **2 0 SITE CHARACTERISTICS**

OU2 is one of 16 OUs at the RFETS and as shown in Figure 2 1 is located on the southeastern side of the RFETS industrial area OU2 contains 22 IHSSs that have been organized into five remediation areas based on contaminated media and type of contamination (i e source vs residual) These five remediation areas include source areas for surface soil contamination source areas for subsurface soil contamination (potential or current) residual areas for surface soil contamination residual areas for subsurface soil contamination and upper hydrostratigraphic unit (UHSU) groundwater contamination The locations of the individual IHSSs are shown on Figure 2 2 A matrix identifying the individual IHSSs in relation to the five remediation areas is presented in Table 2 1

This section provides a brief description of the site geology (Section 2 1) the nature and extent of contamination (Section 2 2) and the fate and transport mechanisms for the chemicals of concern (COCs) (Section 2 3) The information provided in this section is a summary of the site characterization results presented in the preliminary draft OU2 RFI/RI report (DOE 1993) Technical Memorandum No 9 for OU2 (DOE 1994b) and Technical Memorandum No 1 for OU2 (DOE 1995a)

### **2 1 Site Geology and Hydrogeology**

A brief summary of OU2 surficial and bedrock geology is presented below

#### **2 1 1 Surficial Geology**

Surficial geologic units within OU2 consist of alluvial hillslope and man made deposits Alluvial deposits include the Pleistocene aged Rocky Flats Alluvium younger terrace alluvia and various Holocene aged valley fill alluvia Hillslope deposits consist of Holocene aged colluvium and landslide slumps Man made deposits are artificial fills debris dumps and areas of disturbed surficial soil A brief summary of the surficial deposits is presented below

**Rocky Flats Alluvium** The Rocky Flats Alluvium is the topographically highest and oldest alluvial deposit at RFETS The Rocky Flats Alluvium within OU2 caps the pediment surface between South Walnut and Woman Creeks The pediment is completely truncated to the north east and south by these modern drainages The Rocky Flats Alluvium within the OU2 area consists predominantly of beds and lenses of poorly to moderately sorted gravels and sands A few lenses of clay and silt also occur

**Hillside Deposits** Hillside deposits within the OU2 area include several alluvial terrace deposits valley fill alluvium colluvium and landslide slumps Slump features belong to two categories 1) areas along the hillsides which exhibit evidence of mass movement of surficial soil and possibly bedrock materials along relatively distinct ruptures or glide surfaces and 2) areas of hummocky topography reflecting downslope creep of surficial soils but no observable rupture surface

**Man Made Deposits** Man made deposits within the OU2 area have been identified using information from historical reports air photography and geologic field mapping Three general categories of man made deposits have been identified soil and debris dumps disturbed ground and artificial fill

## **2 1 2 Bedrock Geology**

Bedrock geologic units within the OU2 area consist of claystones siltstones and sandstones The No 1 Sandstone is considered the basal part of the Arapahoe Formation All lower bedrock units are considered to be a part of the upper Laramie Formation (DOE 1993)

**Arapahoe Formation No 1 Sandstone** Subsurface investigations have shown that the Arapahoe Formation No 1 Sandstone (No 1 Sandstone) is a distinct bedrock unit separate in geologic characteristics from the underlying Laramie Formation Most of the No 1 Sandstones are predominantly fine to medium grained and represent deposition in low to moderate flow regimes The No 1 Sandstone is the stratigraphically highest sandstone encountered within the OU2 area It is stratigraphically located from 0 to 20 feet below the overlying surficial deposits The sandstone directly underlies the Rocky Flats Alluvium along a medial paleoscur beneath OU2 Prior to deposition of the Rocky Flats Alluvium erosion of the claystone/siltstone material in this area created the paleoscur The resulting subcrop area beneath the Rocky Flats Alluvium is an important feature in that it allows vertical groundwater flow to the No 1 Sandstone from the overlying alluvial units

**Laramie Formation** The Laramie Formation is a fresh to brackish water non marine deposit Lithologic logging of the upper Laramie Formation suggests that in this area it is largely composed of claystone with lenses of fine grained sandstone The most common upper Laramie Formation lithologies encountered in boreholes within the OU2 area are claystones and silty claystones The upper Laramie Formation sandstone or siltstone interbeds are approximately 10 feet thick except where interbeds are stacked on top of each other Where sandstone interbeds are stacked a thicker sandstone sequence results The sandstone interbeds are commonly separated by thin siltstone or claystone layers

## **2 2 Nature and Extent of Contamination**

The remediation targets selected for OU2 were compared against the maximum detected concentrations of each COC to identify those contaminants that warrant further consideration in the CMS/FS process If the maximum concentration was less than the respective remediation target the COC was eliminated from further consideration For the purposes of identifying and evaluating potential remedial technologies only those COCs with concentrations in excess of the OU2 remediation target levels were retained in the CMS/FS process The results of this comparison for surface soils subsurface soils and groundwater are provided in Tables 2 2 2 3 and 2 4 respectively The comparison of maximum concentrations of each COC against the selected remediation targets provides a more restrictive basis for assessing nature and extent of

contamination and development of remedial alternatives than the use of average concentrations therefore the volume estimates could represent an over estimation of actual contaminant volumes

Several of the IHSS located in OU2 do not contain COCs in concentrations exceeding the remediation targets developed in Technical Memorandum No 1 These IHSSs include the East Spray Fields (IHSS 216 2 3) Gas Detoxification Site (IHSS 183) Oil Burn Pit Site No 2 (IHSS 153) Pallet Burn Site (IHSS 154) and Reactive Metal Destruction Site (IHSS 140) Since these IHSSs do not require remedial actions based on the remediation targets they will not be addressed further in this document

For purposes of identifying and evaluating potential remedial technologies the extent of contamination for each IHSS was compared against the selected remediation targets to identify those IHSSs which warranted further consideration in the CMS/FS process The results of this comparison are presented in Table 2 5 Further discussion concerning the nature and extent of contamination by remediation area is provided in the following paragraphs

### **2 2 1 Source Areas for Surface Soil Contamination**

Source areas for OU2 surface soils have been defined as localized areas of elevated contaminant concentrations that have historically acted as sources of contamination This consists of the former drum storage site (903 Pad) and the 903 Pad Lip

#### **903 Pad**

The 903 Pad was a graded earthen area located at the southeast corner of the industrial area and was used for storage of waste drums between 1958 and 1967 The drums contained machine oil (primarily lathe coolant consisting of straight chain hydrocarbons with carbon tetrachloride) hydraulic oils vacuum pump oils trichloroethylene (TCE) perchloroethylene (PCE) silicone oils and acetone still bottoms contaminated with either plutonium (Pu) or depleted uranium Contaminated oil reportedly leaked from approximately 420 drums located on the 903 Pad This resulted in the release of an estimated 18 000 liters (5 000 gallons) of liquid and 86 grams (Seed et al 1971) to 126 grams (Krey and Hardy 1970) of Pu 239+240 to the soil environment

In 1960 a radiological survey at the 903 Pad indicated that the pad area and the surrounding (lateral) 10 feet of surficial soils were contaminated with Pu 239+240 and depleted uranium By 1964 evidence of large scale deterioration of drums was reported and fill dirt was placed on highly contaminated areas on the 903 Pad Surveys performed in the Lip Area in 1967 revealed spreading of contamination dispersion (surface transport) was attributed to a heavy rain event Soil and rocks (east and downgradient of the storage area) contaminated by rainwater runoff from the fenced area were hand excavated and deposited inside the 903 Pad fence (DOE 1992)

Drum removal activities from the 903 Pad began in 1968. Following drum removal radiological monitoring detected elevated levels of contamination in the surrounding areas. Contaminant dispersion was attributed to high velocity winds. Radiation monitoring and mapping of the 903 Pad area documented radiological contamination to a depth of 20.3 centimeters (cm) (8 inches).

Fill material for leveling was applied to the 903 Pad in 1969. Additionally, overlay material, soil sterilant, and an asphalt cover were placed over the 903 Pad (DOE 1992). In 1970, 6 inches of coarse road base was applied to the Lip Area.

During monitoring of the 903 Pad in 1971, four hot spots were identified based on radiological surveys. This led to the removal of 31 kilograms (kg) of depleted uranium and up to 10.3 milligrams (mg) of Pu from beneath the asphalt cover. During sampling activities associated with this removal action, an oil layer contaminated with depleted uranium was discovered at two separate boreholes at depths of 45.7 and 76.2 cm (18 inches and 30 inches) respectively at the holes where the 31 kg of depleted uranium were extracted. A clay layer was noted beneath the contaminated zone. At that time, no contamination was found below the clay layer, and it was believed that the layer served as a natural barrier to downward migration of contaminants. However, the draft OU2 RFI/RI identified radiological contamination at decreasing concentrations from 0.6 to 6 meters (2 to 20 ft). Volatile organic compound (VOC) contamination was found at depths to 7.3 meters (24 ft).

### 903 Lip Area

Prior to the addition of an asphalt cap, contamination present at the 903 Pad was transported by winds and surface water runoff (immediately following drum removal activities) and were deposited on soils in an east and southeast trending plume (Krey and Hardy 1970; Seed et al 1971). The analysis of spatial distribution identifies a west to east wind transport mechanism being the dominant dispersal mechanism of Pu 239+240.

Contaminated soil in this Lip Area, identified in the past through Fidler (non intrusive survey equipment) monitoring and laboratory analysis, has been excavated. In 1973, an aerial radiological survey detected radioactive concentrations in the Lip Area that were greater than 2,000 counts per minute (cpm). In 1975, eight 55 gallon drums of soil were removed from the contaminated Lip Area as a pilot test for excavation techniques. Ambient air monitoring during excavation did not detect Pu in concentrations that would endanger onsite workers, the public, or the environment. In 1976, approximately 113.3 cubic meters (m<sup>3</sup>) (4,000 cubic feet) of soil were removed from within the Lip Area. Soil removal activities were conducted again in 1978, covering an estimated 3,995 m<sup>2</sup> (43,000 ft<sup>2</sup>) at a depth of approximately 3.5 cm (9 inches) for soil that exceeded 2,000 cpm. This targeted area is believed to have been the topical depression southeast of the 903 Pad. After each removal action, the excavated area was covered with clean fill and revegetated. Historical aerial photographs verify this conclusion.

Although several removal actions have been conducted in the 903 Lip Area recent sampling has detected the presence of Pu 239+240. The vertical profile of actinides in the fill region follows a unique profile with depth. In general the highest activity is found in the top 3 cm (1 2 inches) followed by a significant decrease between 6 and 9 cm (2 4 and 3 4 inches) then by an increase in actinide activity beneath the fill level. The increase of actinide activity in the top 3 cm (1 2 inches) of fill material cannot be explained by previous wind dispersion.

Soil sampling conducted during the RFI/RI indicated levels of Pu 239+240 in the Lip Area above the 1 800 pCi/g remediation target. The extent of contamination was denoted by generating OU2 isopleth maps of Pu 239+240 based on RFI/RI analytical results for the COCs (See Figures 2 3 and 2 4). During the Lip Area removal activities in 1976 and 1978 an additional 20 cm of fill were added. The areal extent of current Lip Area contamination is approximately 10 000 m<sup>2</sup> (107 600 ft<sup>2</sup>) in size. Assuming a depth of 40 cm (including the 20 cm of fill material that were added to the previously excavated Lip Area) the volume of contaminated media that exceeds the remediation target is estimated to be 4000 m<sup>3</sup> (141 200 ft<sup>3</sup>) of soil.

No other COCs have been detected at concentrations greater than the OU2 remediation target.

## **2 2 2 Residual Surface Soil Contamination**

Residual surface soil contamination is defined as contamination present in the upper 5 cm (2 inches) of impacted soil primarily to the east and southeast of the 903 Lip Area. This consists of most of the buffer zone east of the 903 Pad and Lip Area. Those OU1 surface soils contiguous to OU2 which are contaminated with low levels of plutonium are being administratively addressed under OU2. This is because this area of OU1 surface soil is believed to have been contaminated by the 903 Pad Area.

Contamination in the surface soil residual area is attributed primarily to wind dispersion from the 903 Pad source area. A small amount of Pu contamination originated from the stack effluent of the production facilities. The spatial distribution of Pu 239+240 where this region is adjacent to the source area is displayed in Figure 2 5. The data in this table indicate a large variability in Pu 239+240 activity near the source area between samples taken by Colorado Department of Public Health and Environment (CDPHE) sampling protocols and those which were taken by Rocky Flats sampling techniques.

Plutonium 239+240 was detected in OU2 residual surface soils in concentrations greater than the OU2 remediation target level. Two sample locations associated with two 2 5 acre plots outside of the Lip Area detected Pu 239+240 activity greater than 1800 pCi/g outside of the 903 Pad Lip Site. In one of these plots two field duplicates were taken using the Rocky Flats sampler. One sample exhibited 380 pCi/g and the other showed 11 000 pCi/g. This variability probably occurred due to wind erosion, some solubility and leachability and the hot particle phenomenon. As defined by Winsor and Whicker (1979) a hot particle has an activity above

450 pCi/g and it is usually an agglomeration of numerous host soil grains and  $\text{PuO}_2$ . Studies conducted at Rocky Flats indicated a significant variation in the sizes and spatial distributions of the Pu particles in the soil. Pu oxides are insoluble under OU2 soil conditions and are subject to heterogeneous dispersion. Therefore a large variability in a short sampling interval is not surprising. Additionally the soil sampling techniques at Rocky Flats collect large quantities (up to 5 kg) of which only a small fraction is processed and analyzed. This could explain the variation in actinide activities shown in Figure 2.5

Other possible causes of the large variability in actinide activity across the remediation area is prior vehicle and construction disturbance and past cleanup practices. A 1994 air photograph taken by the Radiological Assessment Group showed that large vehicular and/or construction disturbances occurred in at least one sampling plot. Based on the required sampling protocol requiring 5 to 10 subsamples in the middle of the plot, samples could have been taken in a highly disturbed location which is unrepresentative of the original loading.

Extensive excavation in 1976 and 1978 in the first plot to the southeast of the 903 Pad could also have affected the distribution of actinide activity. Since Pu activities prior to the cleanup exceeded 10 000 pCi/g, wind and runoff during cleanup probably spread the original contamination to the southeast. This would explain the high readings (up to 5 700 pCi/g) in this area.

Based on current measurements, the volume of contaminated media that exceeds the remediation target is estimated to be 1 070  $\text{m}^3$  (1 400  $\text{yd}^3$ ) assuming a 2 hectare (5 acre) plot at a 5 cm (2 inches) depth. However, the large variability in measured Pu 239+240 activity just east southeast of the 903 Pad has implications in delineating potential cleanup areas. It is probable that expanded sampling and analysis of Pu 239+240 activity in this region could result in a larger area of concern, perhaps by as much as 20.2 hectares (50 acres). This would increase the remediation volume by 10 700  $\text{m}^3$  (14 000  $\text{yd}^3$ ). Further study should be conducted to determine the actual extent of Pu 239+240 activity in this region.

In regard to vertical distribution of actinide activity in this surface soil source region near the 903 Pad, more than 90 percent (and over 95 percent of detected activity outside of the Lip Area) of the Pu 239+240 is confined to the upper 12 cm (5 inches) of the soil, regardless of the soil series or distance and direction from the 903 Pad (Litaor et al. 1994). The vertical profile depends on the initial loading of Pu 239+240 on the soil surface; the higher the initial loading, the greater the potential for translocation of actinides with depth. Also, the actinides are most closely associated with soil organic matter. Sequential extraction experiments showed that 45 to 65 percent of the Pu 239+240 is associated with organic matter, 20 to 40 percent is bound to sesquioxides, and 10 to 15 percent probably resides as  $\text{PuO}_2$  particles loosely associated with primary minerals (Litaor et al. unpublished data).

### 2 2 3 Source Areas for Subsurface Soil Contamination

Source areas for OU2 subsurface soil contamination have been defined as IHSSs which were used as storage or disposal sites for low level hazardous or mixed wastes. These areas may or may not currently contain waste material (e.g. spent solvents, cutting oils, and drums). Additional field characterization efforts have been initiated to better quantify the nature and extent of contamination at these source areas. This characterization and discussions on the nature and extent of contamination will be included in the engineering evaluation/cost analysis (EE/CA). Subsurface soil source areas for OU2 include the Mound Site and Trenches T 1 through T 13. These removal actions are expected to be remedial in nature.

Based on information in the draft RFI/RI report for OU2, contaminant concentrations for the soils beneath the 903 Pad currently do not exceed the remediation targets. Because there is a groundwater contaminant plume beneath the 903 Pad, it is assumed that the 903 Pad was and may currently be a source of contaminants to the groundwater (the remediation targets for groundwater are much lower than the targets for subsurface soils).

The Mound Site was used to dispose of drums containing depleted uranium and beryllium contaminated lathe coolant. Some drums containing PCE were also placed in the Mound Site. In the past, waste materials were removed from the Mound Sites and were either shipped offsite for disposal or sent to Building 774 for treatment.

The trenches (T 1 through T 13) were used primarily for the disposal of sanitary sewage sludge contaminated with uranium and plutonium, and flattened empty drums contaminated with uranium (DOE 1992). Plutonium and uranium contaminated asphalt planking from the solar evaporation ponds may have been placed in trenches T-4, T 11, and/or other trenches. It is also suspected that some solvent bearing wastes were placed in some of the trenches; however, it is not known which of the trenches received the wastes. Records indicate that approximately 125 drums containing depleted uranium chips and small amounts of lathe coolant were buried in Trench T 1. This trench is believed to have also received drums containing metal turnings, still bottoms, cemented cyanide waste, and copper alloy. Trench T 9 is reported to contain scrap metal from production operations.

The trenches are currently being characterized as part of an effort to delineate the extent of contamination in the Northeast Trench area. The only COC which was detected in the subsurface soil source area at concentrations exceeding the OU2 remediation target level was PCE. However, it is recognized that only limited characterization data are available for the burial trenches. For the purposes of identifying potential remedial technologies and alternatives, technologies that could be utilized to remediate a wide range of contaminants and debris were evaluated.

## **2 2 4 Residual Subsurface Soil Contamination**

Residual subsurface soil contamination is defined as contamination remaining in subsurface soils after completion of subsurface source removal actions. The subsurface soils consist of all OU2 soils deeper than approximately 5 cm (2 inches) (EPA 1992a)

Characterization efforts conducted in support of the RFI/RI for OU2 identified PCE as the only COC occurring at concentrations greater than the OU2 remediation target level. Concentrations of PCE exceed the remediation target of 2 210 mg/kg at two borehole locations (10191 and 24793). Both borehole locations lie in or near Trench T 3 at the Northeast Trench Area and may be addressed in any remedial actions taken at the Subsurface Soil Source Area. It is suspected that waste materials and liquid solvent waste stored in Trench T 3 may have been encountered during the drilling of the boreholes. No other boreholes exceeded the remediation target.

The extent of contamination that exceeds the remediation targets could significantly increase if modeling demonstrates that lower levels of PCE in the subsurface soils are not protective of groundwater. In this case, the remediation target level could potentially be lowered. Such a groundwater protection based remediation target will be developed in the detailed analysis of alternatives.

## **2 2 5 Upper Hydrostratigraphic Unit (UHSU) Groundwater Contamination**

The nature and extent of groundwater contamination is addressed first by describing the conceptual hydrogeologic model of the site, followed by a discussion of the nature and extent of contamination observed during the RFI/RI.

### **2 2 5 1 UHSU Conceptual Model**

Within OU2, the UHSU is comprised of variably and seasonally saturated parts of the unconsolidated surficial deposits: the No. 1 Sandstone that is in hydraulic connection with the saturated surficial materials and weathered claystones of the Arapahoe and/or Laramie Formations. Laramie Formation sandstones that subcrop beneath the No. 1 Sandstone or saturated surficial soils also are considered part of the UHSU. The unconsolidated surficial deposits consist of the Rocky Flats Alluvium, colluvium, valley fill alluvium, and disturbed ground. Groundwater is present in the UHSU under unconfined conditions, except where parts of the No. 1 Sandstone are overlain by claystone, which results in both confined and unconfined conditions within the sandstone. Figure 2.6 presents a schematic cross section of the site hydrostratigraphy.

The UHSU is located over the relatively flat divide of South Walnut Creek and Woman Creek and is truncated to the north, east, and south along these drainages. The thickness and geometry of the UHSU geologic units are controlled by bedrock paleotopography, specifically the north and south paleoridges that generally trend east-northeast, the medial paleoscar that

lies between the two paleoridges other bedrock paleotopographic lows and steps that exist on the weathered bedrock paleotopographic surface and depositional channels of the sandstones included in the UHSU A bedrock paleotopographic map is provided in Figure 2 7

Groundwater flow within the UHSU is complex because of variations in groundwater flow directions interactions between geologic units and variations in degree of saturation and saturated thickness Groundwater flow within the UHSU is strongly influenced by the bedrock paleotopography and the geometry and hydraulic characteristics of the unconsolidated deposits comprising the UHSU Groundwater within the UHSU generally is found within the area described as the medial paleoscur (Figure 2 7) and generally flows towards the northeast In the area of Trench 2 immediately south of the drum storage site groundwater locally flows to the south during high water table conditions

The areal extent and saturated thickness of the UHSU within the medial paleoscur vary seasonally The north and south paleoridges restrict groundwater outflow from the alluvium to the north and south The medial paleoscur is erosionally truncated along the north facing hillslope of South Walnut Creek UHSU groundwater discharges from the No 1 Sandstone as seeps from this area

Groundwater recharge to the UHSU within OU2 occurs as direct infiltration of precipitation and by lateral and downward seepage from surface water features such as ditches Recharge to the No 1 Sandstone probably occurs from infiltration of precipitation and surface water through the overlying unsaturated surficial deposits vertical groundwater flow from the overlying saturated surficial deposits and inflow from the saturated sandstone units upgradient (west) of OU2

## **2 2 5 2 UHSU Contamination**

Contamination in the UHSU groundwater exists throughout OU2 Source areas for UHSU groundwater contamination are not clearly defined but may originate from one or more waste disposal or storage sites as defined in the RFI/RI For purposes of the CMS/FS groundwater contamination is considered to be non IHSS specific Since the source of surface water contaminants (seeps) is believed to be groundwater the seeps are being addressed as part of the groundwater remediation effort With implementation of appropriate groundwater controls the seeps can be remediated Therefore separate surface water contaminants and potential exposure pathways are not being considered as part of this technical memorandum

Results of the Phase II RFI/RI investigation have indicated that the contamination is confined to the UHSU Characterization efforts conducted in support of the RFI/RI indicate the presence of organics and radionuclides in sufficient quantities to be deemed as COCs within the UHSU of the 903 Pad Area the Mound Area and East Trenches Area Contaminants detected include 1 1 dichloroethene carbon tetrachloride (CCl<sub>4</sub>) chloroform methylene chloride PCE TCE vinyl chloride americium (Am) 241 and Pu 239+240 All of the COCs exceed their respective remediation target

Groundwater sampling has shown several plumes of VOC contamination in the Rocky Flats Alluvium and the No 1 Sandstone originating at the 903 Pad the Mound Area and the Northeast Trenches Area. Once in the sandstone the contaminated groundwater flows from the 903 Pad to the Mound Area and finally to the Northeast Trenches Areas. As groundwater passes beneath each of these sources contaminant concentrations increase (DOE 1995b).

The potential for the occurrence of dense nonaqueous phase liquids (DNAPLs) in groundwater appears to be greatest for  $\text{CCl}_4$ , PCE and TCE based on the observation of groundwater concentrations that exceed 1 percent of the chemical solubility. Potential DNAPLs in groundwater could exist beneath the 903 Pad ( $\text{CCl}_4$ , PCE and TCE) in the vicinity of Trench T 2 (PCE and TCE) north and northeast of the mound site (PCE) and northeast of Trench T 3 and north of Trench T-4 in the Northeast Trenches (TCE). Direct evidence of DNAPLs in groundwater was not observed during the Phase II RFI/RI programs (DOE 1993).

Pu 239+240 was observed in filtered and unfiltered UHSU groundwater samples collected from wells east and southeast of the 903 Pad. Radionuclide contamination could be associated with high concentrations of VOCs observed in the UHSU in the 903 Pad Source Area (DOE 1995b).

The extent of groundwater contamination was estimated using analytical results from the second quarter 1992 sampling event. For each of the seven organic COCs the RFI/RI report provides an isoconcentration map for both the alluvial/colluvial and the No 1 Sandstone units. In general the unit specific isoconcentration maps for each of the COCs are consistent with each other which may be an indication that their sources and transport mechanisms are similar.

To provide an overall estimation of the contaminant volume for groundwater the areas exceeding the remediation targets for each individual COC were superimposed to establish a single plume map that encompassed all of the contaminated areas. Contaminant data from both the alluvial/colluvial and No 1 Sandstone units were combined in the event that the selected remedy is not able to isolate the contaminants between the two units. The combination of the two geologic units also provides a larger estimate of the contaminant volumes.

After the combined plume map was generated it was combined with the alluvial/colluvial saturated thickness map for the second quarter 1992 sampling event. The second quarter of 1992 was chosen as the baseline for the volume estimate since this time period represents the greatest known saturated thickness of the hydrogeologic units. Since the contaminant plume extends beyond the zone that is saturated year round some contaminants may be trapped in the vadose zone as the groundwater recedes.

Based on the distribution of groundwater contamination within the UHSU and the UHSU's maximum saturated thickness the quantity of contaminated groundwater was estimated in the Phase II RFI/RI report to be about 27 million gallons during wet periods. This estimate was calculated using an average total porosity of 0.361. The total porosity is based on data collected from the Rocky Flats Alluvium in OU4 (The paper by Fedors and Warner 1993).

contains Rocky Flats Alluvium porosity and hydraulic conductivity data from only one point #1 Qrf in OU2. The porosity at this location is 0.506 and is from a very fine grained clayey Rocky Flats Alluvium. This location is on the distal end of the OU2 pediment and porosity values from this area are considered less representative of the 903 Pad area than OU4 data. This paper does not address the Arapahoe Formation No. 1 Sandstone.)

No measured values of effective porosity of the Rocky Flats Alluvium are known. The volume of contaminated groundwater present in the UHSU varies seasonally because of the fluctuating water levels. The estimated volume of contaminated groundwater during a drier period (first quarter of 1992) is about 9 million gallons.

## **2.3 Contaminant Fate and Transport**

Contaminant migration pathways including intermedia (transport between two separately defined media) and intramedia (transport within an individual medium) for source surface soil, residual surface soil, source subsurface soil, residual subsurface soil, and groundwater areas are presented below.

### **2.3.1 Source Areas for Surface Soil Contamination**

#### **2.3.1.1 Intermedia Pathways**

The intermedia pathway of surface soil contaminant migration from the 903 Lip Area is the transport of Pu-239+240 from the top 40 cm (16 inches) of soil within IHSS 155 to deeper soils. Transport mechanisms from surface soil to subsurface soils appear to be limited.

Colloid facilitated transport of radionuclides may be associated with rain or snowmelt. Data for samples of infiltrating water strongly suggest a short residence time of 2 to 4 hours for freely flowing water in the soil system. This short residence time inhibits a continuous interaction between the soil and the flowing water, which helps explain the uniformity in alkalinity, specific conductance, and pH across the study site and between sampling depths. A soil water monitoring system (SWMS) was installed to gather real time data on freely flowing soil interstitial waters, water content, matric potential, soil temperature, and precipitation. Measurements of soil moisture, matric potential, precipitation, and volume of collected freely flowing waters suggest that preferential flow might occur under both unsaturated and saturated conditions.

However, during the summer of 1993, an evaluation of water and actinide movement was conducted by studying natural and simulated rain events. The actinide activities in water samples from depths of 55 to 80 cm did not exceed 10 pCi/l even after a rain simulation of a 100 year event. This restriction in actinide movement may occur due to a strong affinity between organic soil components and plutonium oxides. Additional rain simulations were run in the summer of 1994 to assess the potential for actinides to be transported downhill by runoff. Three sequential rain simulations of 100 year flooding events were conducted. In these runs

most of the actinides were relatively immobile (Figure 2 8) However when the soil moisture regime was changed from aridic to aquatic significant amounts of Pu 239+240 and Am 241 were transported to groundwater in at least one occurrence This supports the previous detection of Plutonium in groundwater from a well installed in the colluvium

### **2 3 1 2 Intramedia Pathways**

Although several removal actions including the placement of clean fill have been conducted in the 903 Lip Area recent sampling has confirmed the presence of Pu 239+240 in the clean fill This movement of actinides within various surface soil horizons as demonstrated by the increase of actinide activity in the top 3 cm (1 2 inches) of fill material cannot be explained by previous wind dispersion

Based on the site history and other information burrowing animals ant colonies and especially earthworms (which have all been observed at OU2) are believed to be the upwardly mobile transport mechanisms for residual contamination that remained in the Lip Area (Litaor et al 1994) Earthworm activity is probably the pathway for vertical migration of radionuclides within the top 40 cm (15 7 inches) of the soils investigated (Litaor et al 1994) Geological features of the site such as lateral discontinuities and macroporosity could also contribute to the redistribution of contaminants

The current dominant intramedia transport of surface soil Pu 239+240 contamination from the 903 Lip Area is biological activity (e g earthworms) Rodents may also enhance transport flow Earthen mounds produced by ants may have increased wind erosion of the soil surface and affected eolian transport of soil particles containing Pu 239+240 (Winsor and Whicker 1979) Transport mechanisms (wind dispersion and precipitation runoff) potentially exist if the soils or the current vegetative cover are disturbed as was experienced during the original cleanup efforts Air monitoring results conclude that after the pad was installed in 1969 levels of wind dispersed contamination were significantly reduced Subsequent air monitoring during the excavation efforts in 1976 and 1978 did not indicate dispersion of contamination via windblown particulates Currently this wind dispersion transport mechanism does not appear to be significant sue to the presence of a natural vegetative cover and the absence of significant sources of actinide particles exposed to the ground surface

Rain simulations conducted to evaluate surface transport mechanisms found that actinides did not migrate in runoff waters until the end of the second sequential 100 year rain event This indicates that such migration can only occur under the most extreme and unlikely conditions

### **2 3 2 Residual Surface Soil Contamination**

The contaminant fate and transport mechanisms for residual surface soil contamination is the same as those described under Source Area for Surface Soil Contamination (Section 2 3 1)

### **2 3 3 Source Areas for Subsurface Soil Contamination**

#### **2 3 3 1 Intermedia Pathways**

The intermedia pathway of subsurface soil contaminant migration is the transport of contaminants from subsurface soil to groundwater. Characterization of contaminants in the subsurface soil sources has not been completed.

VOCs semivolatile organic compounds (SVOCs) and/or radionuclides leaked released to subsurface soils at the 903 Pad Drum Storage Site the Mound Site and Trenches T 1 through T 13 as a result of past waste disposal practices. VOCs and SVOCs previously migrated downward through the vadose zone to the saturated zone.

In general COCs may have migrated into the subsurface zones as dissolved constituents or as non aqueous phase liquids (NAPLs). Along with this migration residual contamination in the vadose zone and in the saturated zone likely occurred.

Characterization of contamination present in the subsurface soil source has not been completed. However the presence of PCE above OU2 remediation target levels has been confirmed in the vicinity of Trench T 3.

PCE is essentially immiscible in water. However PCE migration could have occurred by several mechanisms. The migration could have occurred directly if a sufficient amount (pool) of PCE existed to overcome capillary pressures by diffusion or by dissolution in another more mobile NAPL. If the latter case were the main mechanism for downward PCE migration one would also expect significant concentrations of the accompanying NAPL.

PCE has the ability to partition to the vapor phase via volatilization and the liquid phase via dissolution. Following migration into the subsurface liquid phase PCE will redistribute and come to rest either as disconnected ganglia and filaments (known as residual) or in the form of potentially mobile pools perched upon capillary barriers (Poulsen et al 1992).

The ultimate penetration depth of PCE following a ground surface release depends on the volume released and the distance to the water table. Also important are the percentage of pore space occupied by the PCE and the irreducible water saturation as well as the degree of lateral spreading exhibited by the migrating PCE.

The spatial distribution of the PCE migration paths depends on the bedding structure of the porous medium with horizontal bedding promoting lateral spreading. The distribution of water content the PCE fluid properties and the manner in which PCE was introduced in the subsurface also affect the spatial distribution of PCE migration paths (Poulsen et al 1992).

As previously stated in Section 2 3 1 analysis of SWMS measurements of soil moisture matric potential precipitation and volume of collected freely flowing waters suggests that

preferential flow occurs under both unsaturated and saturated conditions. This preferential flow may have allowed the fluid transport of dissolved PCE from the subsurface soil medium to the groundwater during snowmelt and precipitation events.

### **2 3 3 2 Intramedia Pathways**

Past and present intramedia transport has been and is primarily controlled by the flow of interstitial waters through preferential pathways within the subsurface soil source area as described in Section 2 3 1. These transport mechanisms (e.g., colloidal dissolution) are contaminant specific.

### **2 3 4 Residual Subsurface Soil Contamination**

The intermedia pathway of residual subsurface soil contaminant migration from the Northeast trenches is the transport of contaminants from subsurface soil to groundwater. COCs in groundwater suggest that residual contamination in the vadose zone or saturated zone beneath the Northeast trenches may persist and act as a secondary source of contamination to groundwater. Intermedia and intramedia transport of PCE in the subsurface soil residual area will behave as described in Section 2 3 3 above.

### **2 3 5 Upper Hydrostratigraphic Unit Groundwater Contamination**

#### **2 3 5 1 Intermedia Pathways**

The primary intermedia pathways affecting groundwater or affected by groundwater include the transport of contaminants from surface soils to groundwater, transport of contaminants from subsurface soils to groundwater, and the discharge of groundwater at seep or surface water locations. Transport of surface soil contaminants, i.e., Pu 239+240, was addressed in Section 2 3 1. Transport and fate of COCs in subsurface soils is described in Section 2 3 3. Discharge of contaminants at seep and surface water locations occurs where groundwater exits the UHSU in response to hydraulic gradients or where the UHSU is truncated along the OU2 hillsides.

NAPLs movement through subsurface soils may have been relatively rapid, especially if the soils were dry and the quantity of NAPLs was large. Fractures or macropores in the subsurface soils could have facilitated movement of NAPLs to groundwater. The fluid migration likely resulted in residual contamination in the vadose zone and possibly the underlying saturated zone. Dissolved phase contaminants not held in the vadose zone ultimately reach the saturated zone where they mix with groundwater in the saturated groundwater system. NAPLs have been observed in Trench T 3 (DOE 1995b) and are suspected in other OU2 contaminant disposal areas.

A NAPLs source in the subsurface soils can result in multiple incidents of dissolved contaminant releases to groundwater during percolation of precipitation and recharge to

groundwater Residual NAPLs in subsurface soils can act as a long term contaminant source to groundwater and greatly increase the time period of remediation

## **2 3 5 2 Intramedia Pathways**

The primary intramedia pathways include the transport of dissolved contaminants in groundwater present in both the Rocky Flats Alluvium and associated unconsolidated geologic materials and the No 1 Sandstone and dissolved contaminant transport between these water bearing strata Contaminant sources within the saturated UHSU include residual DNAPL globules and ganglia in the water bearing zone pore space and possibly DNAPLs pooled on low hydraulic-conductivity zones that serve as capillary barriers within the UHSU or stratigraphically trapped on top of the Lower Hydrostratigraphic Unit (LHSU) PCE or other chlorinated solvents may also be dissolved in light non aqueous phase liquid (LNAPL) pools that remain in the groundwater capillary fringe Over time these denser solvents may leach from the LNAPL pools into the groundwater in the dissolved phase Such DNAPL and LNAPL sources provide a long term source of VOC contaminants to groundwater

Once in groundwater Pu 239+240 may migrate as particulate and dissolved fractions Pu 239+240 has been reported to sorb to particulates including colloids Pu 239+240 activity observed in groundwater as a percentage of total sample activity is distributed primarily in the particulate (40 percent) and dissolved (53 percent) fractions Although colloids comprise about 92 percent of the total particle concentration in the groundwater only about 6 percent of the total plutonium activity is associated with colloidal particles while 94 percent is associated with particulates Pu 239+240 thus appears to be very particle reactive and to also exhibit significant dissolved phase association (Harnish et al no date)

Groundwater contamination in the saturated UHSU beneath the 903 Pad flows to the northeast along the medial paleoscur Contaminant flow also occurs to the south southeast towards Trench T 2 during the spring high water period During low water periods groundwater flow continues to the northeast along the medial paleoscur but flow to the south southeast becomes intermittent as water levels decrease The predominant contaminants present in plumes emanating from the 9033 Pad Area are VOCs VOC contaminants are found in groundwater in saturated portions of the Rocky Flats Alluvium and colluvium and have migrated vertically to the underlying No 1 Sandstone west of the 903 Pad and in the area of the Northeast Trenches Groundwater contaminants from the 903 Pad may extend to the Southeast Trenches area at low concentrations Contaminated groundwater from the UHSU discharges at seeps near Trench T 2 and along the north facing hillslope of South Walnut Creek

## 3 0 Corrective/Remedial Action Objectives

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### **3 0 CORRECTIVE/REMEDIAL ACTION OBJECTIVES**

The C/RAOs consist of media specific goals for protecting human health and the environment. Remediation may practice protectiveness through reducing exposure such as capping an area or limiting access or by reducing contaminant level, mobility or toxicity. The C/RAOs were originally developed in Technical Memorandum No. 1 (DOE 1995a). In response to regulatory comment, they have been revised as follows:

- Remediate contaminated surface and subsurface soils to non zero chemical specific ARARs or to be considered (TBC) values as appropriate
- In the absence of ARARs/TBCs, remediate contaminated surface and subsurface soils so that they are within an acceptable risk range (excess cancer risk greater than  $10^{-4}$  to  $10^{-6}$  or a hazard index of greater than one for noncarcinogens) considering the reasonable maximum exposure scenario
- Remediate subsurface soils to levels which will ensure protection of groundwater as prescribed by ARARs/TBCs identified for groundwater considering site specific subsurface soil/groundwater interactions. (Colorado State groundwater ARARs have been identified for OU2 based on the current groundwater use classification at the RFETS. If the use classification is changed in the future, new ARARs will be identified based on the new classification)
- Remediate groundwater to non zero chemical specific ARARs/TBCs as appropriate
- In the absence of ARARs/TBCs, remediate contaminated groundwater that would result in acceptable risk based concentrations considering the reasonable maximum exposure scenario (total excess cancer risk of greater than  $10^{-4}$  to  $10^{-6}$  or a hazard index greater than one for noncarcinogens)

## 4.0 Remedial Technologies & Process Options

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## **4 0 REMEDIAL TECHNOLOGIES AND PROCESS OPTIONS**

For the purpose of this technical memorandum the terms technology or technology type refer to general groupings of technologies potentially applicable to general response action (GRA). The term process option describes a specific process that is available for consideration within a particular technology type. A representative process option (RPO) is a single process option that is representative of similar process options within a given technology type. The RPOs are selected as the basis for developing and evaluating various remedial alternatives which eliminates the need to conduct a comparative evaluation of multiple similar alternatives.

This section documents the identification and screening of remedial technologies and process options for the purpose of identifying RPOs that can be applied to developing remedial alternatives. The identification and screening of technologies and process options was performed according to CERCLA guidance (EPA 1988) which included

- Establishing media specific GRAs for OU2
- Identifying potentially applicable remedial technologies and process options for each contaminated medium
- Screening the identified remedial technologies and process options against specific criteria to eliminate technologies and process options that are not applicable to site specific conditions or may not achieve the C/RAOs for the particular media and
- Selecting RPOs to develop remedial alternatives

The GRAs that were established for OU2 are discussed in Section 4.1. A discussion of procedures and resources used to identify potentially applicable remedial technologies and process options is presented in Section 4.2. The screening procedure, screening criteria, and results of screening are presented in Section 4.3. Descriptions of the remedial technologies and process options that were retained after the screening process are provided in Appendices A (Surface and Subsurface soil) and B (Groundwater). The selection of the RPOs used to develop remedial alternatives is discussed in Section 4.4.

### **4.1 Identification of General Response Actions**

GRAs are strategies that describe general actions that will satisfy the C/RAOs established for OU2. Media specific GRAs were developed for each environmental medium exhibiting COCs at concentrations above the selected remediation target for OU2. The media for which GRAs were developed include surface soil, subsurface soil (including IHSS specific source controls), and groundwater. Identified GRAs may be implemented individually or in combination with other GRAs to meet the C/RAOs. The GRAs identified for contaminated

media include no action institutional controls containment *in situ* treatment removal and *ex situ* treatment A general description of each GRA is provided below

- **No Action** Required by CERCLA as a benchmark for comparison against other remedial action alternatives Implies that no direct action will be taken to alter the existing situation other than short and long term monitoring of site conditions
- **Institutional Controls** Refers to controls based on legal and/or management policies which minimize public exposure to potential contaminants Examples include legally restricting land use by zoning provisions or modification of deeds and site access controls such as fencing
- **Containment** Consists of those actions which would minimize or prevent migration of contaminants by wind dispersion or storm water erosion mechanisms for surface soil and by infiltration and vadose zone transport mechanisms for subsurface soil and the saturated zone
- ***In Situ* Treatment** In general *in situ* treatment refers to treatment of contaminants in place *In situ* treatment actions would remove detoxify and/or immobilize contaminants using chemical thermal physical or biological technologies
- **Removal** Includes remedial actions such as soil/waste excavation and groundwater extraction which are used to remove and/or consolidate contaminated media Also includes transportation and disposal of non hazardous hazardous radioactive and mixed wastes at permitted facilities such as a landfills storage vaults injection wells or underground repositories
- ***Ex Situ* Treatment** This action is similar to *in situ* actions with the exception that the contaminated media are extracted or removed prior to treatment *Ex situ* actions separate or concentrate detoxify or immobilize contaminants using chemical thermal physical or biological technologies

## **4 2 Identification of Technologies and Process Options**

A comprehensive list of remediation technologies and process options was developed for the RFETS as part of Task 3 of the CMS/FS (EG&G 1994) Resources consulted to compile the comprehensive list of technologies (CLT) (ES 1994) included

- EPA and DOE guidance documents
- Technical publications journals and proceedings

- Computerized remediation and waste treatment databases including EPA's Vendor Information System for Innovative Treatment Technologies (VISITT) Risk Reduction Environmental Laboratory (RREL) Treatability Database and Alternative Treatment Technology Information Center (ATTIC) and
- Existing RFETS documents including treatability studies and interim measures/interim remedial action (IM/IRA) reports

Information provided in the CLT and additional EPA and DOE guidance documents was used to identify technologies and process options which are potentially applicable to remediate the contamination present in OU2. The specific COCs for each medium presented in Section 2.1 were used as the basis for establishing three media specific contaminant groups

- Surface soil contaminated with radionuclides
- Subsurface soils (including subsurface soil source areas) contaminated with VOCs SVOCs metals and radionuclides and
- UHSU groundwater contaminated with radionuclides and VOCs

The comprehensive technology list for each medium provided the initial starting point for the screening and evaluation of the remedial technologies and process options. The lists of technologies are grouped under surface soils subsurface soils and groundwater and are presented later in this section

#### **4.3 Screening of Technologies and Process Options**

The list of technologies and process options for each medium was screened against established criteria for implementability effectiveness and cost. The goal of the screening process was to eliminate those technologies and/or process options that obviously could not be implemented because of OU2 site specific factors thereby reducing the number of remedial technologies and process options for consideration in the development of remedial alternatives

The screening process was applied in two stages. The first stage was an initial technology screen based on technical implementability. The second stage included an evaluation of effectiveness institutional implementability and cost. Process options were screened and evaluated under the assumption that they would be implemented as the primary remedial treatment process. Therefore several process options were not retained after screening because they were only applicable as a secondary treatment or a component of a potential remedial alternative. The following subsections present the methods criteria and results of the screening of technologies and process options a description of the remedial technologies and process options that passed the screening criteria and a discussion regarding the selection of representative process options retained for the development and detailed analysis of remedial alternatives

#### 4 3 1 Initial Technology Screen Technical Implementability

The initial technology screen is a fatal flaw analysis based solely on technical implementability. This stage of screening required the review of site characteristics and specific information for each process option to identify any factor that would prevent the technology or process option from being implemented at OU2 for a specified contaminated environmental medium. Some factors affecting technical implementability that were considered during the fatal flaw analysis were

- Characteristic properties of contaminants
- COC concentrations
- Water table depth
- Depth to bedrock
- Horizontal and vertical extent of contamination
- Hydrogeologic characterization and
- Surface topography

If any factor or combination of factors that would prevent a process option from being implemented was identified, that process option was eliminated from further consideration and the reason was documented. The initial technology screening process eliminated subsequent development of more detailed information for those technologies and process options that were determined to be obviously inadequate.

The results of the initial technology screen for surface soils are presented in Figure 4.1. This figure illustrates the relationship between surface soil GRAs, remedial technologies, and process options. Process option descriptions and screening comments are also presented. Shaded entries represent those technologies and process options that were eliminated during the initial technology screen.

Five surface soil technologies were removed from further consideration (Figure 4.1) based on the results of the initial technology screen. Three containment technologies (surface controls, groundwater controls, and vertical barriers), one *in situ* technology (chemical/physical), and one *ex situ* technology (thermal) were removed because associated process options were not applicable to the thin horizon of surface soils and/or could not be justified as a primary treatment process without inclusion of other process options. In addition, numerous process options were removed from consideration from the retained technologies for the reasons specified in the screening comments column.

Results of the initial technology screen for subsurface soils are presented in Figure 4 2 Surface controls and groundwater controls were eliminated as containment technologies because associated process options are not appropriate as primary treatment options by themselves and do not warrant further consideration in the feasibility study (FS) *Ex situ* biological treatment was eliminated as a technology type because associated process options are not practical for the volume of contaminated material or appropriate for the treatment of radionuclides Thirteen other process options were eliminated for the reasons specified in the screening comments

Results of the initial technology screen for groundwater are presented in Figure 4 3 Storage of contaminated groundwater was eliminated from further evaluation because this is not a long term solution *In situ* solidification/stabilization technologies were eliminated for the reasons identified in the screening comments column It is assumed that any *ex situ* groundwater treatment performed will be conducted at the existing onsite water treatment plant Therefore all of the *ex situ* process options were eliminated except for the onsite water treatment plant Twelve other process options were eliminated for the reasons specified in the screening comments

Descriptions of remedial technologies and process options for soils (surface and subsurface) and groundwater that passed the initial technical implementability screen are presented in Appendices A and B respectively

#### **4 3 2 Technology Evaluation**

The second stage of screening included an evaluation of effectiveness institutional implementability and relative cost The evaluation of effectiveness was deemed to be the most important criterion in the technology evaluation stage Specific remedial technologies and process options were evaluated on their effectiveness relative to other technologies or process options within the same technology type The evaluation of effectiveness was based primarily on

- The potential effectiveness of process options in handling the estimated areas or volumes of media and meeting the preliminary remediation goals (PRGs) and other C/RAOs
- The potential impacts to worker safety human health and the environment during the construction and implementation phase and
- The degree to which the processes are proven and reliable with respect to the contaminants and conditions at the site

The evaluation of institutional implementability included consideration of

- The ability to obtain the necessary permits for onsite and offsite actions

- The availability of treatment storage and disposal services and
- The availability of necessary equipment and skilled workers to implement the technology

Because of the limited information on some of the innovative technologies it was not always possible to evaluate these technologies at the same level of detail as the demonstrated and traditional remedial technologies and process options. Typically innovative remedial technologies were judged to be institutionally implementable and were retained for further evaluation either as a selected process option or as represented by another similar process option within the corresponding technology type. Figure 4 4 presents the results of the technology evaluation for surface soil. All of the process options for surface soil were retained for further evaluation.

Figure 4 5 presents the results of the technology evaluation for subsurface soil. *In situ* biological treatment is not expected to meet C/RAOs for the subsurface COCs but has been retained as an applicable technology to treat non halogenated petroleum hydrocarbon in the source areas if necessary. *In situ* pneumatic fracturing, electrokinetics and electroacoustical soil decontamination were eliminated because they will not likely be effective at OU2. Four *ex situ* process options were also eliminated because they are not effective for treatment of the COCs or are difficult to implement.

Figure 4 6 presents the results of the technology evaluation for groundwater. Sheet piling was eliminated from further evaluation because it will be very difficult to implement at OU2. The multi layer cap was also eliminated due to its high capital cost. All of the remaining process options were retained for further evaluation.

#### 4 4 Representative Process Options

All remedial technologies and process options that met the criteria for the initial technology screen and technology evaluation are presented as unshaded entries in Figures 4 4 through 4 6. RPOs were selected from retained process options for given technology types based on engineering judgement. Innovative technologies were only selected as RPOs if the literature documented that they would provide better treatment, fewer or lower adverse effects and/or lower costs than more established process options. The ability of the innovative technology or process option to be implemented within a realistic timeframe was also taken into consideration.

The goal of the last screening step was to select one or two process options to represent each retained technology type. The selected RPOs for OU2 surface soils, subsurface soils and groundwaters are presented in Tables 4 1 through 4 3 respectively. These tables also provide the GRAs and remedial technology types for each of the selected RPOs. For surface soil 14 RPOs were selected (see Table 4 1). For subsurface soil 21 RPOs were selected (see Table 4 2) and 17 RPOs were selected for groundwater (see Table 4 3). Further evaluation of the

selected RPOs is presented in Section 5.0 of this document. This additional process option analysis allowed for development and evaluation of distinct remedial alternatives.

## 5.0 Potential Remedial Alternatives

## **5 0 POTENTIAL REMEDIAL ALTERNATIVES**

This section develops the remedial alternatives for the five remediation areas. This action is consistent with the IAG statement of work which states: "The range of alternatives shall include at a minimum options to reduce the toxicity, mobility, or volume of wastes, but which vary in the types of treatment, the amount of wastes treated, and the manner in which long term residuals or untreated wastes are managed; options involving containment with little or no treatment; options involving both treatment and containment; and a no action alternative."

The remedial alternatives involving treatment and/or containment were assembled using combinations of the RPOs presented in Section 4.4 of this document. The RPOs and other suitable process options of the same technology types will be evaluated in depth during the detailed analysis of alternatives (DAA) and presented in the CMS/FS report. Because this section includes a reasonable range of alternatives, an initial screening of alternatives prior to the DAA will not be conducted. All remedial alternatives will be evaluated in detail during the DAA. Descriptions of the remedial alternatives are presented in the following subsections.

### **5 1 OU2 Surface Soils Source Alternatives**

Seven remedial alternatives for the OU2 surface soil sources were developed. These alternatives are designed to address remediation of Pu 239+240 contamination. Alternative concept diagrams are presented in Figures 5.1 through 5.3. General descriptions of each alternative are presented in the following sections.

Assumptions and considerations used during the assembly of alternatives for surface soil sources include:

- Disposal will be performed at an onsite or offsite treatment, storage, or disposal (TSD) facility such as Envirocare, Inc. or the Nevada Test Site (NTS), and
- Air sampling and radiological monitoring will continue under existing or modified programs to monitor for possible migration at concentrations above the remediation target level.

#### **5 1 1 GRA No Further Action**

##### **Alternative 1 No Further Action with Long Term Monitoring**

The no further action alternative consists of long term monitoring for the surface soil source (Figure 5.1). No additional remedial activities or institutional controls will be implemented for this alternative.

The long term radiological monitoring of surface soil and airborne dust would be performed to evaluate potential contaminant migration at levels above the OU2 remediation target level. If monitoring detects migration of contaminants above the selected OU2

remediation target for plutonium a contingency plan would be implemented The plan would evaluate the risks associated with the contamination and potential strategies to address the migrating contaminants that pose a threat to human health or the environment The contingency plan may include implementation of one or any combination of the other surface soil alternatives presented below Long term surface soil and air monitoring would be conducted until the COC concentrations in the surface soils are consistently measured below the established OU2 remediation target

This alternative does not meet C/RAOs It is included only as a baseline for comparison with other alternatives

### **5 1 2 GRA Institutional Controls**

#### **Alternative 2 Deed Restrictions and General Access Restrictions**

Alternative 2 includes deed restrictions site access restrictions and long term radiological monitoring of the surface soils and airborne dust The deed restrictions would be implemented to legally restrict use of the contaminated areas within the site Installation of fencing around the contaminated areas (Figure 5 1) and long term security of the site would be implemented as necessary to limit access

Similar to the no further action alternative the institutional controls alternative includes long term air sampling and radiological monitoring of surface soils to evaluate potential contaminant migration at unacceptable levels A contingency plan would be developed to address risks associated with contaminant migration The contingency plan may include implementation of one or any combination of the other surface soil alternatives presented below Long term monitoring would be conducted until the plutonium concentration is consistently measured below the selected remediation target

### **5 1 3 GRA Containment**

#### **Alternative 3 Cap in Place**

Alternative 3 includes an engineered cover (cap) that would be placed over the areas with surface soil contamination above the selected remediation target (Figure 5 1) The cap and the site terrain would be graded and seeded Installation of fencing around the contaminated areas (Figure 5 1) and long term security of the site would be implemented to limit access Deed restrictions security and fencing would be installed as necessary to limit access to the site Long term radiological air monitoring of the site would also be performed A contingency plan would be developed to address risks associated with contaminant migration

The cap would be designed to decrease contaminant mobility by reducing air and surface water dispersion of surface soils and by reducing infiltration of surface water Construction of the cap and site grading would direct surface water runoff away from the affected areas The cap would include an asphalt cover or an engineered cap to reduce erosion from wind and surface water

In addition to construction of a cap fencing around the site would be installed and site security would be implemented to limit access to the affected areas Long term air monitoring of the site would be performed to monitor for potential contaminant migration above the OU2 remediation target level through airborne dust

This alternative would reduce contaminant migration to air surface water and groundwater It would also reduce the potential for exposure to concentrations of plutonium greater than the selected remediation target

#### **5 1 4 GRA *In Situ* Treatment**

##### **Alternative 4 *In Situ* Stabilization/Solidification**

Alternative 4 includes *in situ* stabilization/solidification of surface soils It would reduce the mobility of the contaminants by reducing the potential for these contaminants to migrate as dust become entrained with surface water runoff or infiltrate further into subsurface soils (Figure 5 2) The surface soils would be mixed in place with stabilization/solidification agents to produce a treated matrix that is resistant to both physical and chemical degradation If long term monitoring detected migrating contamination above the OU2 remediation target level a contingency plan would be implemented

Stabilization involves mixing the soil with a stabilization agent which chemically converts the contaminant into a less soluble and/or less toxic form Solidification entails mixing the soil with a solidification agent that produces a leach resistant physically durable solid product The stabilization and solidification processes usually result in a volume increase of the contaminated matrix due to the addition of treatment agents Treatment agents that could potentially be used for the source surface soil include

- Cements (masonry Portland gypsum or polymeric)
- Lime/pozzolan mixtures (lime/fly ash or lime/blast furnace slag) and
- Encapsulation binders (bitumen thermoplastic polymers or catalyzed polymers)

*In situ* stabilization/solidification would be performed using a variety of common types of mixing equipment For surface soils backhoe mounted equipment such as mixing injectors rippers disk harrows and plows can be used Depending on the site conditions during the remedial activities as determined by monitoring dust suppression measures and/or dust collection equipment may be required

Following *in situ* stabilization or solidification the treated areas may be graded covered with clean topsoil and seeded to provide a vegetative cover These measures would be implemented to reduce the infiltration of surface water into the treated areas increase evapotranspiration and reduce the potential for erosion and exposure to the treated soil

Long term radiological air monitoring would be required to ensure that airborne particulates from the site are not above acceptable contaminant levels. Fencing would be installed around the affected areas and site security would be implemented to limit potential contact with the treated soils.

The stabilization/solidification would reduce the toxicity and/or mobility of the radioactive contamination. The fencing and site security components of this alternative would reduce the potential for exposure to the treated soils.

## **5.1.5 GRA Removal**

### **Alternative 5 Excavation and Disposal**

Alternative 5 would include the removal of all contaminated surface soil that exceeds the selected remediation target for plutonium and subsequent onsite or offsite disposal (Figure 5.2). The excavated soil would be analyzed to determine the appropriate disposal requirements. The disturbed areas would be backfilled with clean soil and reseeded to provide a vegetative cover. During and after the excavation activities, surface soil sampling would be performed to ensure that all of the contamination above the OU2 remediation target has been removed. No long term radiological monitoring would be required once it had been demonstrated that remediation target levels were achieved.

Excavation of surface soils would be performed using conventional earthmoving equipment such as backhoes, bulldozers, and graders. Depending on the site conditions during the remedial activities, dust suppression or dust collection measures will be required. Monitoring of airborne particulates during excavation would establish the requirements for dust control measures. Following excavation, the contaminated soils would be containerized utilizing drums, crates, and/or rolloff boxes and transported to the appropriate disposal facility by a conveyor system, trucks, and/or railcars.

The excavated soils would be disposed either onsite at the RFETS or at an appropriate offsite TSD facility. Analytical testing of the excavated soils would be required to ensure compliance with disposal requirements.

Clean fill from either an onsite or an offsite borrow source would be used as backfill for the excavations. Seeding of the affected areas may be performed to establish a vegetative cover. The benefits of a vegetative cover would be similar to those described in Section 5.1.4.

Removal of the contaminated soils and disposal at a permitted facility would eliminate potential onsite exposure to plutonium above the selected remediation target.

**5 1 6 GRA Ex Situ Treatment**  
**Alternative 6 Excavation and Soil Washing**

Alternative 6 encompasses the excavation of contaminated surface soils and transportation to an onsite facility for treatment by soil washing methods (Figure 5 3) After soil washing the clean fraction of the treated soil would be used as backfill for the excavations The contaminated fraction would be transported to an onsite or offsite disposal facility After backfilling of the excavations the affected areas may be seeded to establish a vegetative cover During and after the excavation activities surface soil sampling would be performed to ensure that all of the contamination above the selected remediation target has been removed No long term radiological monitoring would be required once it had demonstrated that remediation target levels were achieved

Soil washing is a treatment process in which particle sizing and separation techniques are used to separate relatively contaminated soil fractions (typically the finer grained fraction) from relatively clean coarser fractions Excavated soils are first wet scrubbed and sized to separate coarse sized soil fractions from fines The coarse size soils are returned to the excavation and the finer soils are subjected to attrition scrubbing with surfactants chelating agents or other conditioning agents to further concentrate the contaminants Following treatment by soil washing the clean fraction of the soil as determined by a radiological survey would be returned to the site for use as backfill in the excavations The contaminated fraction and the treatment residuals (e g washing solutions) would either be treated further and/or disposed at an appropriate onsite or offsite disposal facility

After backfilling of the excavations the affected areas would be seeded to provide a vegetative cover Additional clean fill may be required to replace the soil lost as fines during washing activities The benefits of a vegetative cover would be similar to those described in Section 5 1 4

Removal of the contaminated soils from the site would eliminate potential exposure to plutonium contaminated soil above the selected remediation target

**5 1 7 GRA Ex Situ Treatment**  
**Alternative 7 Excavation, Ex Situ Stabilization, and Return to Excavation**

Alternative 7 would include excavation of the contaminated surface soils and onsite stabilization treatment (Figure 5 3) After treatment stabilized soils that meet radiological requirements would be used onsite as backfill for the excavations Soils not meeting the requirements would be disposed at an appropriate TSD facility After backfilling the excavations with the treated soils the affected areas may be seeded to allow for establishment of a vegetative cover No long term radiological monitoring would be required once it had been demonstrated that remediation target levels were achieved

The excavation activities for this alternative would be the same as those described in Section 5.1.5 (Alternative 5). Sampling and monitoring activities during the excavation would also be the same as those described for Alternative 5. Containerization and transportation of the excavated soil to an onsite treatment facility would be required.

Treatment of the excavated soils would involve mixing with a stabilization agent which would chemically convert the contaminant into a less soluble and/or less toxic form. This process would result in a volume increase of the contaminated matrix. Treatment agents that could potentially be used are presented in Section 5.1.4. This alternative would require installation of a temporary or permanent onsite treatment facility capable of performing stabilization. When soils have been stabilized they will be returned to the excavated area covered with topsoil and revegetated similar to Alternative 6.

The stabilization would reduce the toxicity and/or mobility of the contaminants contained within the soil matrix. The fixation of radionuclides in the soil matrix would eliminate potential onsite exposure to plutonium contaminated soil above the selected remediation target. Institutional controls would be added as required.

## **5.2 OU2 Subsurface Soils Source Alternatives**

Eleven potential remedial alternatives for the OU2 subsurface soil sources were developed. The alternatives are illustrated in Figures 5.4 through 5.8 as concept flow diagrams. These alternatives are further described and evaluated in EE/CAs for subsurface soil sources.

Assumptions used during the assembly of remedial alternatives for subsurface soil sources include:

- Pyrophoric uranium chips exist in at least some of the buried drums in Trench T<sub>1</sub>
- Some drums buried at the site may have leaked resulting in the release of contaminants to the subsurface soils in the trench and
- Heavy metals, organics, and radionuclides are assumed to be potentially present in addition to the risk based COCs

### **5.2.1 GRA No Further Action**

#### **Alternative 1 No Further Action with Long Term Monitoring**

The no further action alternative includes intrinsic remediation and long term monitoring for the subsurface soil source (Figure 5.4). No additional remedial activities or institutional controls would be implemented for this alternative.

The monitoring component of the no further action alternative would consist of periodic soil sampling to monitor natural contaminant degradation and groundwater monitoring to evaluate potential contaminant migration. If monitoring detects migration of contaminants above the OU2 remediation target, a contingency plan would be implemented to evaluate the risks associated with the contamination and develop potential strategies to address the migrating contaminants that pose a threat to human health or the environment. The contingency plan may include implementation of one or any combination of the other subsurface soil source alternatives as presented below. The monitoring program would be conducted until the COC concentrations in the subsurface soils and groundwater are below the OU2 remediation target.

This alternative does not meet C/RAOs. It is included only as a baseline for comparison with other alternatives.

## **5.2.2 GRA Institutional Controls**

### **Alternative 2 Deed Restrictions and General Access Restrictions**

Alternative 2 includes deed restrictions, general access restrictions, and long term monitoring of the subsurface soils and groundwater. The deed restrictions would be implemented to legally restrict use of the contaminated areas within the site. No construction, excavation, or other intrusive activities would be allowed, reducing potential exposure to the contaminants. Installation of fencing around the contaminated areas and long term security of the site would be implemented to limit access.

The long term monitoring would be similar to that described for the no further action alternative. A contingency plan would be developed and monitoring would continue until the COC concentrations in the subsurface soils and groundwater are below the OU2 remediation target.

## **5.2.3 GRA Containment**

### **Alternative 3 Cap in Place**

Alternative 3 includes installation of an engineered cover (cap) over the areas where subsurface soil contamination exceeds selected remediation targets. Grading of the cap and the site terrain would be performed. Deed restrictions and general access restrictions would be implemented to limit potential exposure to the contaminated soils. Long term monitoring of the subsurface soils and groundwater would also be performed for this alternative.

The cap would be designed and constructed to decrease contaminant mobility by reducing infiltration of surface water into the contaminated areas. Grading of the cap and site terrain would direct surface water runoff away from the affected areas. The cap would include a vegetative cover to reduce erosion from wind and surface water and increase evapotranspiration. The cap would not reduce migration of contaminants through the groundwater exposure pathway.

The deed restrictions and general access restrictions would be consistent with Alternative 2. The long term monitoring would be similar to that described for the no further action

alternative A contingency plan would be developed and if necessary monitoring would continue the COC concentrations in the subsurface soils and groundwater are below the OU2 remediation target Groundwater would be monitored to measure any contaminant contribution from the subsurface soil source

The capping and the institutional controls implemented for this alternative would reduce potential exposures to the subsurface soil sources and minimize downward leaching of contaminants to groundwater

#### **5 2 4 GRA Containment**

##### **Alternative 4 Cap in Place and Install Vertical Barrier**

Alternative 4 includes installation of an engineered cover (cap) over the subsurface soil source areas and installation of a vertical barrier around the contaminated areas (Figure 5 5) This alternative is the same as Alternative 3 with the addition of a vertical barrier The vertical barrier could consist of a slurry wall or synthetic membrane wall The appropriate type of vertical barrier for the site conditions will be determined in the DAA The vertical barrier which would be tied into the engineered cover system and competent bedrock would reduce the mobility of contaminants from the subsurface soil sources by reducing the flow of groundwater through the area As with Alternative 3 grading of the cap and surface terrain would reduce the mobility of the contaminants by reducing infiltration of surface water into the contaminated areas The containment system would be designed to be passive with no significant long term maintenance requirements No dewatering or active groundwater collection/treatment system within the contaminated areas would be installed

#### **5 2 5 GRA In Situ Treatment**

##### **Alternative 5 Thermally Enhanced Soil Vapor Extraction (SVE), Enhanced Bioremediation, and Cap**

Alternative 5 for the subsurface soil source (Figure 5 5) includes thermally enhanced soil vapor extraction (TSVE) to treat the VOCs and bioremediation for treatment of SVOCs An engineered cover would be installed to reduce infiltration of surface water and contain the other contaminants (radionuclide and metals) remaining in the subsurface soils Similar to Alternative 3 this alternative includes deed and access restrictions and long term monitoring of subsurface soils and groundwater

The TSVE system utilizes heat and vacuum pressure to volatilize and remove organic contaminants Offgas from the TSVE would be treated using granular activated carbon or an equivalent treatment system to remove volatilized organics The sorbed collection media would require treatment recycle or disposal Potential offgas treatment alternatives will be evaluated in the DAA

Enhanced bioremediation would be implemented to degrade SVOCs in the subsurface soil This will involve supplying oxygen moisture and/or nutrients to the contaminated soils

to increase the naturally occurring degradation of contaminants. As with Alternative 3, the cap would reduce potential contaminant mobility, exposures, and infiltration of surface water, and prevent human and environmental contact with source media.

The deed restrictions and general access restrictions would be consistent with Alternative 2. The long term monitoring would be similar to the no further action alternative. A contingency plan would be developed and monitoring would continue until the COC concentrations in the subsurface soils and groundwater are below the OU2 remediation target. Groundwater monitoring would be performed to measure any contaminant contribution from the subsurface soil source.

The TSVE and the enhanced bioremediation included in this alternative would significantly reduce the concentrations of VOCs and SVOCs in the subsurface soil source. The capping and the institutional controls implemented for this alternative would reduce potential exposures to the subsurface soil sources.

#### **5.2.6 GRA *In Situ* Treatment**

##### **Alternative 6 TSVE, Enhanced Bioremediation, *In Situ* Stabilization, and Cap**

Alternative 6 includes all of the technologies presented in Alternative 5, including TSVE, enhanced bioremediation, and capping, with the addition of *in situ* stabilization of the subsurface soils. Cap and site grading would be performed and deed and general access restrictions would be implemented. As with Alternative 5, long term monitoring of the subsurface soils and groundwater would be performed.

*In situ* stabilization would be used to reduce the toxicity and mobility of the metal and radionuclide contaminants by producing a treated medium that is resistant to both physical and chemical degradation, as described in Section 5.1.4. Stabilization would be performed after the completion of TSVE and enhanced bioremediation. Following the stabilization of the subgrade soils, the affected areas would be capped with an engineered cover, as described in Section 5.2.4.

Implementation of this alternative would result in a significant reduction of potential exposure to contaminants above selected remediation targets. The *in situ* treatment of the contaminants would result in a reduction in the toxicity and mobility of the COCs. Capping would reduce the potential for exposure to the remaining contaminants and would minimize infiltration.

#### **5.2.7 GRA *In Situ* Treatment**

##### **Alternative 7 Free Liquid Removal, *In Situ* Stabilization, and Cap**

Alternative 7 for the subsurface soil source (Figure 5.6) includes free liquid removal, *in situ* stabilization, and capping of the affected areas. Also included with this alternative are deed and general access restrictions and long term monitoring.

Free liquid removal would be accomplished by installation of temporary extraction wells and/or piping into the subsurface soils. Conventional pumping techniques would be used to remove any free liquids from the subsurface soils. The removed liquids would be subject to analytical testing to evaluate concentrations. If liquids removed from the subsurface soils meet the waste acceptance criteria (WAC) they would be transported to an onsite disposal facility or offsite to an appropriate TSD facility for treatment and/or disposal.

Following free liquid removal, stabilization and capping would be implemented as presented for Alternative 6. As with the no further action alternative, long term monitoring of the subsurface soils and groundwater would be performed.

The free liquid removal and the stabilization would significantly reduce the mobility and toxicity of contaminants in the subsurface soils. The capping would reduce the mobility of contaminants and would also reduce the potential of exposure to the subsurface soils. The deed and general access restrictions would reduce the potential for exposure to the subsurface soils.

## **5.2.8 GRA *In Situ* Treatment**

### **Alternative 8 *In Situ* Vitrification (with Pretreatment as Necessary)**

Alternative 8 for the subsurface soil source (Figure 5.7) includes *in situ* vitrification with pretreatment as necessary. Also included in this alternative are the institutional controls including deed and general access restrictions and the long term monitoring described for Alternative 2.

*In situ* vitrification utilizes heat generated between electrodes installed in the subsurface soils to melt the contaminated matrix. During the vitrification process, the inorganic wastes are transformed into a molten, vitreous mass that, when cooled, forms a glass-like matrix that is leach resistant and that does not need secondary containment. Offgas collection and treatment would be required to treat contaminants volatilized during the vitrification process. Offgas collection and treatment systems will be evaluated in the DAA.

The *in situ* vitrification process would result in reductions of toxicity and mobility of the contaminants. The deed and general access restrictions would reduce the potential for exposure to the subsurface soils.

## **5.2.9 GRA Removal**

### **Alternative 9 Excavation and Disposal**

Alternative 9 for the subsurface soil source includes removal and disposal of the subsurface soil sources. The removed materials would be analyzed to determine the appropriate disposal requirements. The disturbed areas would be backfilled with clean soil and reseeded to provide a vegetative cover. During and after the removal activities, soil sampling would be performed to ensure that all of the contamination with concentrations above selected remediation

targets had been removed Long term monitoring may not be required once it was demonstrated that remediation target levels have been achieved

After removal the excavated wastes would be separated containerized and characterized for transport and disposal The waste would be evaluated to determine disposal requirements Depending on the contamination of the soil remaining in place after excavation further remedial activities may or may not be required If required remaining contamination would be controlled using technologies described in Alternatives 2 through 8 or 10 and 11

Clean fill from either onsite or an offsite borrow source would be used as backfill for the excavations Seeding of the affected areas would be performed to allow for establishment of a vegetative cover

Removal of the subsurface soil sources would significantly reduce potential exposures to contaminants that exceed selected remediation targets Backfilling of the excavations would reduce the potential for exposure to the remaining subsurface soil contaminants

#### **5 2 10 GRA *Ex Situ* Treatment**

##### **Alternative 10 Excavation, Organics Removal, and Soil Washing**

Alternative 10 is similar to Alternative 9 except that excavated soils would be treated aboveground using organics removal and soil washing technologies (Figure 5 8) During and after the removal activities soil sampling would be performed to ensure that all of the contamination with concentrations above selected remediation targets was removed Long term monitoring may not be required once it is demonstrated that remediation target levels have been achieved

After excavation and separation drums and their contents will be repackaged as required and the soil will be treated Excavated soil will be treated initially using organics removal technologies After the soils are treated for organics they will be treated using soil washing technologies as discussed in Section 5 1 6 Clean material and soil fractions resulting from soil washing will be returned to the site graded and revegetated All wastes that are not suitable to be returned to the site will be analytically characterized to determine the appropriate disposal requirements and will be managed accordingly

Removal of the subsurface soil sources would significantly reduce potential exposures to contaminants that exceed selected remediation targets Backfilling of the excavations would reduce the potential for exposure to the remaining subsurface soil contaminants

#### **5 2 11 GRA *Ex Situ* Treatment**

##### **Alternative 11 Excavation, *Ex Situ* Stabilization, and Return to Excavation**

Alternative 11 is similar to Alternative 10 except that excavated soils would be treated aboveground using stabilization technologies (Figure 5 8) During and after the removal

activities soil sampling would be performed to ensure that all contamination above selected remediation target levels was removed. Long term monitoring may not be required once it is demonstrated that remediation target levels have been achieved.

After excavation and separation drums and their contents would be repackaged as required and the soils would be treated. Stabilization would be used to reduce the mobility of the contaminants in the excavated subsurface soils by producing a treated medium that is resistant to both physical and chemical degradation as described in Section 5.1.4. The stabilized waste form will be analyzed for VOCs, SVOCs, toxicity characteristic leaching procedure (TCLP) and a radiological survey will be performed. If the wastes meet analytical requirements they will be returned to the excavation, graded and revegetated. Any wastes that do not meet the analytical requirements will be re-stabilized until the requirements are met or they will be disposed at an appropriate onsite or offsite TSD facility. Drummed wastes will be evaluated and disposed at the appropriate TSD facility.

Removal of the subsurface soil sources would significantly reduce potential exposures to contaminants that exceed selected remediation targets. Backfilling of the excavations would reduce the potential for exposure to the remaining subsurface soil contaminants.

### **5.3 OU2 Surface Soils Residual Alternatives**

Seven remedial alternatives for the OU2 residual surface soil remediation area were developed to address Pu 239+240 contamination. These alternatives are illustrated in concept flow diagrams in Figures 5.9 through 5.11. The same assumptions and considerations presented under source area surface soils (Section 5.1) apply to this remediation area.

#### **5.3.1 GRA No Further Action**

##### **Alternative 1 No Further Action with Long Term Monitoring**

Alternative 1 consists of long term monitoring for the surface soil residual (Figure 5.9). No additional remedial activities or institutional controls would be implemented for this alternative. The long term monitoring of surface soil and airborne dust would be consistent with Alternative 1 for the surface soil source as presented in Section 5.1.1. This alternative does not meet C/RAOs and is included only as a baseline for comparison with other alternatives.

#### **5.3.2 GRA Institutional Controls**

##### **Alternative 2 Deed Restrictions and General Access Restrictions**

Alternative 2 includes deed restrictions, site access restrictions, and long term radiological monitoring of surface soils and airborne dust (Figure 5.9). The components of this alternative are consistent with those presented for Alternative 2 for the surface soil source (Section 5.1.2).

### **5 3 3 GRA Containment**

#### **Alternative 3 Vegetative Cover**

Alternative 3 involves placing a vegetative cover over surface soil contamination (Figure 5 9) This alternative also includes deed restrictions site access restrictions and long term radiological monitoring of surface soils and airborne dust as described in Section 5 1 2

The vegetative cover would include a 6 inch thick layer of organic soil capable of sustaining vegetation The area would be seeded with plants and grasses native to the area to augment the native vegetative cover currently established

Implementation of this alternative would reduce potential exposure to plutonium contamination above the selected remediation target This alternative also reduces migration of surface soils in storm water runoff and as airborne dust

### **5 3 4 GRA Containment**

#### **Alternative 4 Cap in Place**

Alternative 4 includes an engineered cover that would be placed over surface soil contamination areas (Figure 5 10) As with Alternative 3 for surface soil source areas (Section 5 1 3) grading of the cap and the site terrain would be performed and security and fencing would be implemented to limit access to the site Long term air monitoring of the site would be performed

This alternative would reduce contaminant migration via air surface water and groundwater It would also reduce the potential for exposure to plutonium contamination that exceeds the selected remediation target

### **5 3 5 GRA In Situ Treatment**

#### **Alternative 5 In Situ Stabilization/Solidification**

Alternative 5 includes *in situ* stabilization/solidification of surface soil residuals (Figure 5 10) Deed and general access restrictions and long term air monitoring would be implemented This alternative is consistent with that for surface soil sources as described in Section 5 1 4

The stabilization/solidification would reduce the toxicity and/or mobility of the plutonium contamination in soil This alternative would reduce the potential for exposure to the treated soils

### **5 3 6 GRA Removal**

#### **Alternative 6 Excavation and Disposal**

Alternative 6 includes excavating plutonium-contaminated surface soils that exceed the selected remediation target and disposal at an approved onsite or offsite TSD facility (Figure 5 10) The excavated areas would be regraded and seeded to provide a vegetative cover No long term radiological monitoring would be required because the contaminated soils would be removed from the site The components of this alternative are consistent with those described in Section 5 1 5 for the surface soil sources Removal of the contaminated soils and disposal at a permitted facility would eliminate potential exposure to plutonium-contaminated soil that exceeds the selected remediation target

### **5 3 7 GRA Ex Situ Treatment**

#### **Alternative 7 Excavation and Soil Washing**

Alternative 7 includes excavating plutonium contaminated surface soils that exceed the selected remediation target and treating the contaminated soil using soil washing technologies (Figure 5 11) Following the treatment by soil washing the clean fraction of the soil would be returned to the site as backfill for the excavations No long term radiological monitoring would be required because the contaminated soils would be removed from the site and treated The contaminated fraction and the treatment residuals would either be treated further and/or disposed at an appropriate onsite or offsite disposal facility The components of this alternative are consistent with those described in Section 5 1 6 for the surface soil sources Excavation and soil washing would eliminate potential exposure to plutonium contaminated soil that exceeds the selected remediation target

### **5 4 OU2 Subsurface Soils Residuals Alternatives**

Two alternatives for subsurface soils residuals will be evaluated in the DAA They include the no further action and the SVE alternatives The no further action alternatives will be retained for comparison purposes only (Figure 5 12) Selection of SVE is based on the EPA guidance document *Presumptive Remedies Site Characterization and Technology Selection for CERCLA Sites with Volatile Organic Compounds in Soils* (EPA 1993b)

The objective of the presumptive remedies initiative is to use the Superfund program s past experience to streamline site investigations and expedite selection of cleanup actions Presumptive remedies are preferred technologies for common categories of sites based on historical patterns of remedy selection and EPA s scientific and engineering evaluation of performance data on technology implementation Over time presumptive remedies are expected to ensure consistency in remedy selection and reduce the cost and time required to clean up similar types of sites In addition presumptive remedies are expected to be used at all appropriate sites except under unusual site specific circumstances SVE thermal desorption and incineration are the presumptive remedies for Superfund sites with VOC-contaminated soil assuming the site characteristics meet certain criteria

In general the presumptive remedy alternative for subsurface soils residuals at OU2 would utilize SVE (ambient or thermally enhanced) to reduce VOC concentrations in subsurface soils. Soil vapor extraction wells installed in the contaminated areas would volatilize and remove the COCs. The extraction system may be thermally enhanced to increase the efficiency of the volatilization and removal system. This alternative is consistent with that for the subsurface soil source as described in Section 5.2.5 although no bioremediation or stabilization would be performed for the subsurface soil residual. This alternative would include long term monitoring of the subsurface soils and groundwater. The *in situ* SVE would reduce the toxicity of contaminated soil and reduce the potential for exposure to PCE-contaminated soils that exceed the selected remediation target.

The *Feasibility Study Analysis for CERCLA Sites with Volatile Organic Compounds in Soil* (EPA 1994) provides the basis for limiting the analysis of technologies and alternatives when applying the presumptive remedy approach. Information from the feasibility study performed by the EPA will be utilized in the DAA in developing recommendations for the remedial action plan.

## **5.5 Remediation Alternatives for OU2 Groundwater**

Five alternatives are proposed to remediate contaminated UHSU groundwater beneath OU2. A description of each alternative is presented in Table 1.1. The alternatives include:

- No further action
- Institutional controls
- Containment with or without treatment of drainage
- *In situ* treatment and
- Extraction and *ex situ* treatment alternatives

Concept diagrams of the candidate alternatives are provided in Figures 5.13 through 5.14. Proposed implementation of the alternatives is shown on Figures 5.15 through 5.17. Descriptions of onsite water treatment facilities and pertinent treatability testing programs are presented in Technical Memorandum No. 1 for OU2.

Assumptions and considerations used to develop the groundwater remediation alternatives include:

- Surface and subsurface soil sources have been removed and/or remediated

- Groundwater within the UHSU can be remediated using individual alternatives or a combination of containment collection and *in situ* or *ex situ* treatment alternatives
- Existing RFETS onsite water treatment facilities have sufficient capacity or if necessary can be upgraded to process groundwater from OU2
- Existing RFETS onsite water treatment facilities are designed or can be upgraded to treat all of the OU2 COCs to acceptable concentrations and
- The acknowledged limitations of remediating DNAPL contaminated groundwater to selected remediation targets are recognized and alternative remedial strategies may apply

Potential difficulties and limitations inherent in remediating DNAPL contaminated groundwater to federal and state cleanup levels are acknowledged and discussed in EPA's *Guidance For Evaluating the Technical Impracticability of Ground Water Restoration* (EPA 1993a) and *Alternatives For Groundwater Cleanup* (National Research Council 1994). EPA (1993a) presents guidance for assessing the technical impracticability of groundwater remediation for certain site and contaminant conditions and provides guidance for implementing remediation at these sites. Recognized conditions that may limit the practicability of groundwater remediation include complex stratigraphy, low hydraulic conductivity, presence of fractures, and the occurrence of DNAPLs. Although technical impracticability evaluations are typically conducted after a ROD or after remediation has been implemented, precedence exists for conducting technical impracticability evaluations during the CMS/FS. Evaluation of the technical impracticability for groundwater remediation at OU2 will be conducted as part of the DAA.

The natural shape of the medial paleoscar and the geometry of the UHSU and surrounding low hydraulic conductivity bedrock lithologies provide a convenient mechanism for hydraulic control and/or collection of UHSU groundwater at OU2. Extraction wells can be positioned in areas where the hydraulic conductivity and saturated thickness of the UHSU are optimal to maximize groundwater production and areal drawdown. Collection trenches can be situated in areas where the medial paleoscar narrows to maximize groundwater collection with the minimum amount of trench length.

The two primary geologic units of the UHSU that have the greatest areal distribution and exhibit the greatest saturated thickness at OU2 are the Rocky Flats Alluvium and the No. 1 Sandstone. These units appear to contain most of the groundwater at OU2. Because of the importance of these units in the conceptualization and design of any remedial alternative requiring groundwater extraction, injection, or control, discussions of their relevant geologic and hydraulic characteristics are described below.

**Rocky Flats Alluvium** The Rocky Flats Alluvium is the most widely distributed saturated unconsolidated geologic unit underlying OU2. As illustrated in Figure 5.18, the thickest occurrence of the Rocky Flats Alluvium is found in the medial paleoscour where the saturated thickness is also greatest. Groundwater flow in the alluvium in the medial paleoscour is generally to the east-northeast at a gradient of 0.020 ft/ft as measured during March and May 1992. Because the Rocky Flats Alluvium is erosionally truncated to the north-east and south within OU2, all alluvial groundwater is discharged to surface and subsurface seeps along the bounding hillslopes of the South Walnut Creek and Woman Creek drainage basins, except for alluvial groundwater that recharges the underlying consolidated bedrock units.

The horizontal hydraulic conductivity values of the Rocky Flats Alluvium range between  $5 \times 10^{-2}$  and  $4 \times 10^{-5}$  centimeters per second (cm/s) and has a geometric mean of  $6 \times 10^{-4}$  cm/s. Laboratory vertical hydraulic conductivity values range between  $1.3 \times 10^{-7}$  and  $1.2 \times 10^{-8}$  cm/s. These figures are from the Preliminary Draft OU2 Phase II RFI/RI Report. Because the hydraulic conductivity of the Rocky Flats Alluvium is moderately low, passive groundwater collection and extraction methods are most appropriate for this unit. The calculated average groundwater flow velocity is about 120 feet per year, assuming a hydraulic conductivity of  $6 \times 10^{-4}$  cm/s, an average hydraulic gradient of 0.020 ft/ft, and an assumed effective porosity of 10 percent. No measured values of effective porosity of the Rocky Flats Alluvium are known.

**Arapahoe Formation No. 1 Sandstone** The No. 1 Sandstone is a fluvial sandstone channel deposit bounded by the surrounding bedrock strata that typically consist of claystone or siltstone or by the north-facing hillslopes of the South Walnut Creek drainage. The No. 1 Sandstone directly subcrops beneath the Rocky Flats Alluvium in some areas and is separated from the alluvium by bedrock claystone in other areas. Because the No. 1 Sandstone is erosionally truncated along the north-east and south by the South Walnut Creek and Woman Creek drainages, no direct groundwater pathway exists within the sandstone from OU2 to offsite locations. Almost all sandstone groundwater at RFETS discharges to seeps at the surface.

The No. 1 Sandstone was deposited in channel-incised bedrock claystone of the Laramie Formation. Groundwater flow in the sandstone is controlled by the geometry of the sandstone unit and its interaction with the overlying saturated alluvium and the South Walnut Creek and Woman Creek drainages. Groundwater flow in the No. 1 Sandstone is toward the northeast and locally southeast near the Northeast Trenches. The hydraulic gradient ranges between 0.028 ft/ft and 0.1 ft/ft. Measured vertical hydraulic gradients between the Rocky Flats Alluvium and No. 1 Sandstone range between 0.003 ft/ft and 0.019 ft/ft, generally suggesting that the units are hydraulically connected.

The No. 1 Sandstone exhibits moderately low horizontal hydraulic conductivity with measured values ranging between  $3 \times 10^{-3}$  and  $2 \times 10^{-4}$  cm/s and a geometric mean of  $7 \times 10^{-4}$  cm/s. Vertical hydraulic conductivity values range between  $1.1 \times 10^{-4}$  and  $3.1 \times 10^{-9}$  cm/s. These figures are from the Preliminary Draft OU2 Phase II RFI/RI Report. The wide range of vertical hydraulic conductivity values suggests that horizontal layering may be an important hydraulic control in the No. 1 Sandstone. As with the Rocky Flats Alluvium, passive

groundwater collection and extraction methods are most applicable to this formation. However, in areas where the No. 1 Sandstone exhibits greater hydraulic conductivities and large saturated thicknesses, groundwater may be extracted using pumping wells. Calculated groundwater flow velocity values for the No. 1 Sandstone range between 200 and 730 feet per year. These velocities were calculated using a hydraulic conductivity of  $7 \times 10^{-4}$  cm/s, hydraulic gradients ranging between 0.028 ft/ft and 0.1 ft/ft, and an assumed effective porosity of 10 percent.

#### **5.5.1 GRA: No Further Action**

##### **Alternative 1: Intrinsic Remediation**

The no further action alternative (Figure 5.13) provides a baseline for comparison against other alternatives. Long term groundwater monitoring will be conducted as part of this alternative, and an evaluation of natural contaminant degradation (intrinsic remediation) and contaminant migration will be assessed. Intrinsic remediation is the action of natural processes such as dilution, volatilization, biodegradation, adsorption, and chemical reactions to reduce contaminant concentrations to acceptable levels. Consideration of intrinsic remediation requires monitoring and predictive modeling of contaminant migration and degradation rates to determine the feasibility of meeting C/RAOs.

Long term monitoring will be conducted until groundwater no longer poses a threat to human health or the environment. If intrinsic remediation is not effective and contaminant migration occurs, a contingency plan will be implemented to evaluate the associated risks and to develop strategies to address contaminant migration that poses a threat to human health or the environment. The contingency plan may include implementation of one or any combination of Alternatives 2 through 5.

Alternative 1 provides no control of exposure to contaminated groundwater. However, risk reduction may be achieved through intrinsic remediation.

#### **5.5.2 GRA: Institutional Controls**

##### **Alternative 2: Deed Restrictions and Access Restrictions**

Alternative 2 institutional controls includes limiting use of contaminated groundwater through property deed restrictions and minimizing access to contaminated groundwater and groundwater discharge areas (seeps) by the installation of security fences (Figure 5.13). In addition, deed restrictions for groundwater wells may be requested to prohibit water well installation in the area of contaminated groundwater as long as groundwater contamination poses a threat to human health or the environment. Long term monitoring and an intrinsic remediation evaluation also is included in this alternative.

Long term monitoring will be conducted until groundwater no longer poses a threat to human health or the environment. If intrinsic remediation is not effective and contaminant migration occurs, a contingency plan will be implemented to evaluate the associated risks and to develop strategies to address contaminant migration that poses a threat to human health or the

Horizontal barriers or other ground surface treatments may be considered to enhance surface water runoff maximize evapotranspiration and minimize infiltration and percolation of water through subsurface soils. Low maintenance strategies such as natural vegetative covers are preferable. However other horizontal barrier designs will be considered. Use of horizontal barriers or natural surface treatments (caps) may succeed in drying the UHSU so that VOC constituents might be treated using conventional soil vapor extraction technologies. The need and placement of horizontal barriers will be assessed using predictive models during the DAA and will be evaluated in conjunction with capping alternatives proposed for surface and subsurface soil remediation areas.

#### **5 5 4 GRA *In Situ* Treatment**

##### **Alternative 4 *In Situ* Treatment with or without Containment**

Alternative 4 (Figure 5 14) consists of *in situ* treatment using air sparging/soil vapor extraction (AS/SVE) enhanced bioremediation or passive treatment wall technologies. This alternative may include areal or local containment if necessary to enhance *in situ* treatment. Although numerous *in situ* treatment technologies are available these proposed technologies were selected because of their demonstrated effectiveness and implementability.

*In situ* air sparging involves injecting air into the saturated zone to remove dissolved and residual VOCs. Air sparging is coupled with SVE so that VOCs released to the vadose zone from the saturated zone are captured removed and treated. Both halogenated and non halogenated VOCs may be treated using this process. Offgas treatment may be required to meet applicable air quality standards.

*In situ* bioremediation is a process where organic contaminants are completely or partially metabolized by microorganisms present in groundwater. These organisms convert natural and xenobiotic organic compounds into water carbon dioxide and energy. *In situ* bioremediation of VOCs can occur under both aerobic and anaerobic environments depending on the particular constituent. However most chlorinated solvents are only biodegraded under anaerobic conditions through co metabolism using secondary carbon substrates. Conditions that support co metabolic degradation of chlorinated hydrocarbons may be locally present in OU2 groundwater. Enhanced *in situ* bioremediation fosters and optimizes natural *in situ* bioremediation and biotransformation processes that occur in groundwater by introduction of nutrients organic substrates and electron acceptors to the subsurface.

A passive treatment wall is a permeable reaction wall constructed of materials that will degrade VOCs or sorb exchange or precipitate radionuclides. Passive treatment walls are typically installed across the flowpath of a groundwater contaminant plume so that the water passively moves through the permeable part of the wall and contaminants react with the active material in the wall. Passive treatment walls can be constructed so that the active material can be removed disposed and replaced when contaminant breakthrough occurs.

Figure 5 16 shows the proposed locations of *in situ* treatment components of Alternative 4. These preliminary locations were selected based on the site hydrogeology and dissolved contaminant distributions. The proposed AS/SVE unit locations shown on Figure 5 16 are designated with an AS prefix. AS/SVE may be implemented using either trench or well designs depending on the saturated thickness of the UHSU. A passive treatment wall (designated with a PTW prefix on Figure 5 16) is proposed in the area east of the 903 Pad to remediate radionuclides present in groundwater. Proposed enhanced bioremediation locations would be similar to those selected for AS/SVE. Enhanced bioremediation would be used in lieu of AS/SVE if it is determined to be more effective during the DAA.

AS/SVE is proposed for the 903 Pad Mound area Trench T 2 Northeast Trenches and at a location in the narrow part of the medial paleosol north of the Southeast Trenches. AS/SVE will be used to remediate VOCs in both the unconsolidated geologic materials and the No 1 Sandstone. Greater VOC concentrations typically are found in groundwater in the No 1 Sandstone. Predictive modeling will be used to determine the appropriate spacing and location of individual AS/SVE units. If drying of the UHSU can be achieved using containment technologies so that the unconsolidated geologic materials and No 1 Sandstone are drained only SVE may be required to remediate VOCs remaining in the newly created vadose zone in the UHSU.

An 800 foot long passive treatment wall is proposed for the area east of the 903 Pad to remediate radionuclide-contaminated groundwater but passive treatment wall technology may also be considered for remediation of groundwater VOCs. The treatment wall will be constructed so that its base is keyed into low permeability bedrock strata. The reactive part of the treatment wall will be designed so that it can be removed, disposed, and replaced when contaminant breakthrough occurs. Containment barriers may also be used with the passive treatment wall to funnel contaminated groundwater to the wall's active treatment zone.

#### **5 5 5 GRA *Ex Situ* Treatment**

##### **Alternative 5 Extraction with or without Containment, *Ex Situ* Treatment, and Release**

Alternative 5 (Figure 5 14) consists of groundwater extraction *ex situ* treatment at the onsite water treatment plant and release. Areal or local containment may be used to enhance collection and extraction of groundwater and to minimize groundwater recharge. Because of the moderately low permeabilities of the unconsolidated geologic materials and the No 1 Sandstone, groundwater extraction generally will be accomplished using interceptor trenches with the use of pumping where hydraulic conductivities are greater. Treatment of the contaminated groundwater for radionuclides and VOCs will be conducted at an onsite water treatment plant.

Groundwater extraction involves the use of passive or active methods to collect and remove contaminated groundwater from a site. Passive groundwater collection is accomplished by interceptor trenches or horizontal drains. Active groundwater collection is conducted via

pumping Vertical containment may be used to locally control and route groundwater to central collection and extraction areas Capping may be used to minimize groundwater recharge

Figure 5 17 shows the proposed locations of extraction and containment components of Alternative 5 The preliminary locations were selected based on the site hydrogeology and dissolved contaminant distributions About 3 500 linear feet of interceptor trenches are proposed at locations north of the 903 Pad near Seep 56 north of the Mound area near Seep 59 downgradient of Trench T 2 near Seep 64 downgradient of the Northeast Trenches and across the narrow part of the medial paleoscur north of the Southeast Trenches These trenches are designated with an IT prefix on Figure 5 17 Three pumping wells (designated W 1 W 2 and W 3 on Figure 5 17) are proposed beneath and adjacent to the 903 Pad These wells are proposed to locally extract more highly contaminated groundwater in these areas

A 1 200 foot long vertical barrier (designated VB 1 on Figure 5 17) is proposed upgradient (west) of the 903 Pad to minimize groundwater inflow to OU2 A natural soil/vegetative cover may be installed over the areas encompassed by the 903 Pad Mound Trench T 2 and Northeast Trenches to maximize surface water runoff and evapotranspiration so that groundwater recharge is minimized Limiting groundwater recharge will result in lowering the groundwater table reducing the saturated thickness increasing the thickness of the vadose zone and minimizing the quantity of groundwater collected and treated Determination of the effectiveness of groundwater extraction and treatment will be assessed during the DAA Specific interceptor trench or pumping well configurations and locations and the need for containment or capping will be determined using predictive model simulations

## 6 0 Location-& Action-Specific Applicable or Relevant & Appropriate Requirements

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## 6 0 LOCATION AND ACTION SPECIFIC APPLICABLE OR RELEVANT AND APPROPRIATE REQUIREMENTS

The DOE is responsible for identifying those promulgated standards requirements criteria or limitations to be met during implementation of the selected remedy *Applicable* requirements are those cleanup standards standards of control and other substantive requirements criteria or limitations promulgated under federal environmental or state environmental or facility citing laws that specifically address a hazardous substance pollutant contaminant remedial action location or other circumstance at a CERCLA site *Relevant and appropriate* requirements are those cleanup standards standards of control and other substantive requirements criteria or limitations promulgated under federal environmental or state environmental or facility citing laws that while not applicable to a hazardous substance pollutant contaminant remedial action location or other circumstance at a CERCLA site address problems or situations sufficiently similar to those encountered at the CERCLA site Only state standards that are promulgated and identified in a timely manner by the state and are more stringent than federal requirements qualify as ARARs For purposes of identification and notification of state standards the term promulgated means that the standards are of general applicability and are legally binding

In addition to ARARs other non promulgated advisories criteria or guidance documents that are to be considered (TBCs) to supplement an ARAR provision for a particular release may be identified The TBCs are not legally binding However the TBCs can be used when suitable to determine the level of cleanup required to protect human health and the environment

The EPA has established the three ARAR categories The categories are used as guidance since some ARARs do not necessarily fall into this classification system They include the following

- Chemical specific requirements are usually health or risk based numerical values or methodologies which when applied to site specific conditions result in the establishment of numerical values These values establish the acceptable amount or concentration of chemical that may be found in or discharged to the ambient environment via air emissions wastewater discharges or other routes
- Location specific requirements are restrictions placed on the concentration of hazardous substances solely because they occur in special locations Typical location restrictions include areas with sensitive or unique characteristics such as wetlands areas of historical significance or areas situated in locations requiring special precautions because of seismic activity or flood plains
- Action specific requirements are usually technology or activity based requirements or limitations on actions taken with respect to management of the remediation waste or closure of the facility These requirements are triggered by the particular remedial activities that are selected to accomplish a remedy

Chemical specific ARARs/TBCs that were previously identified for OU2 are presented in Tables 2.2, 2.3 and 2.4 for surface soils, subsurface soils and groundwater respectively. Potential location and action specific ARARs/TBCs have been identified for each remedial alternative presented in Section 5.0 and are summarized in Tables 6.1 through 6.5. Location and action specific ARARs/TBCs will be further evaluated and refined and each alternative will be evaluated with respect to compliance with the ARARs/TBCs during the DAA.

As discussed in Section 2.1, IHSSs that are associated with source areas for surface and subsurface soil contamination have been identified as likely candidates for non time critical removal actions. The National Contingency Plan (NCP) states that removal actions under CERCLA Section 104 and removal actions pursuant to CERCLA Section 106 shall to the extent practicable considering the exigencies of the situation attain ARARs under federal environmental or state environmental or facility citing laws [40 CFR 300.415(i)]. As such, the ARARs/TBCs identified in Tables 6.1 and 6.2 should be considered in the design and implementation of source removal actions for surface and subsurface soil.

## REFERENCES

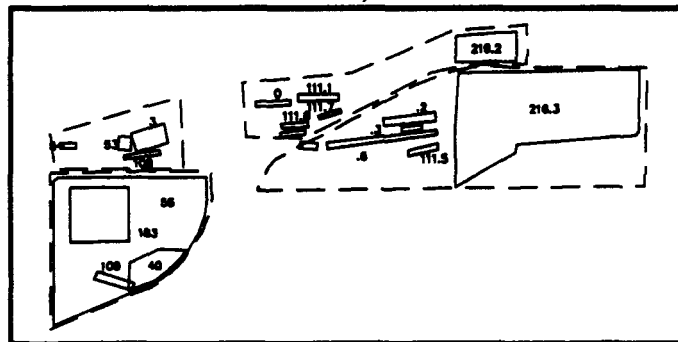
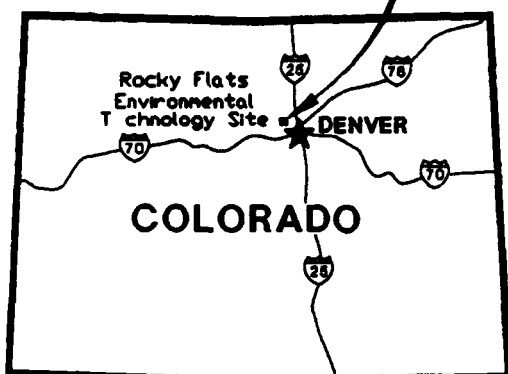
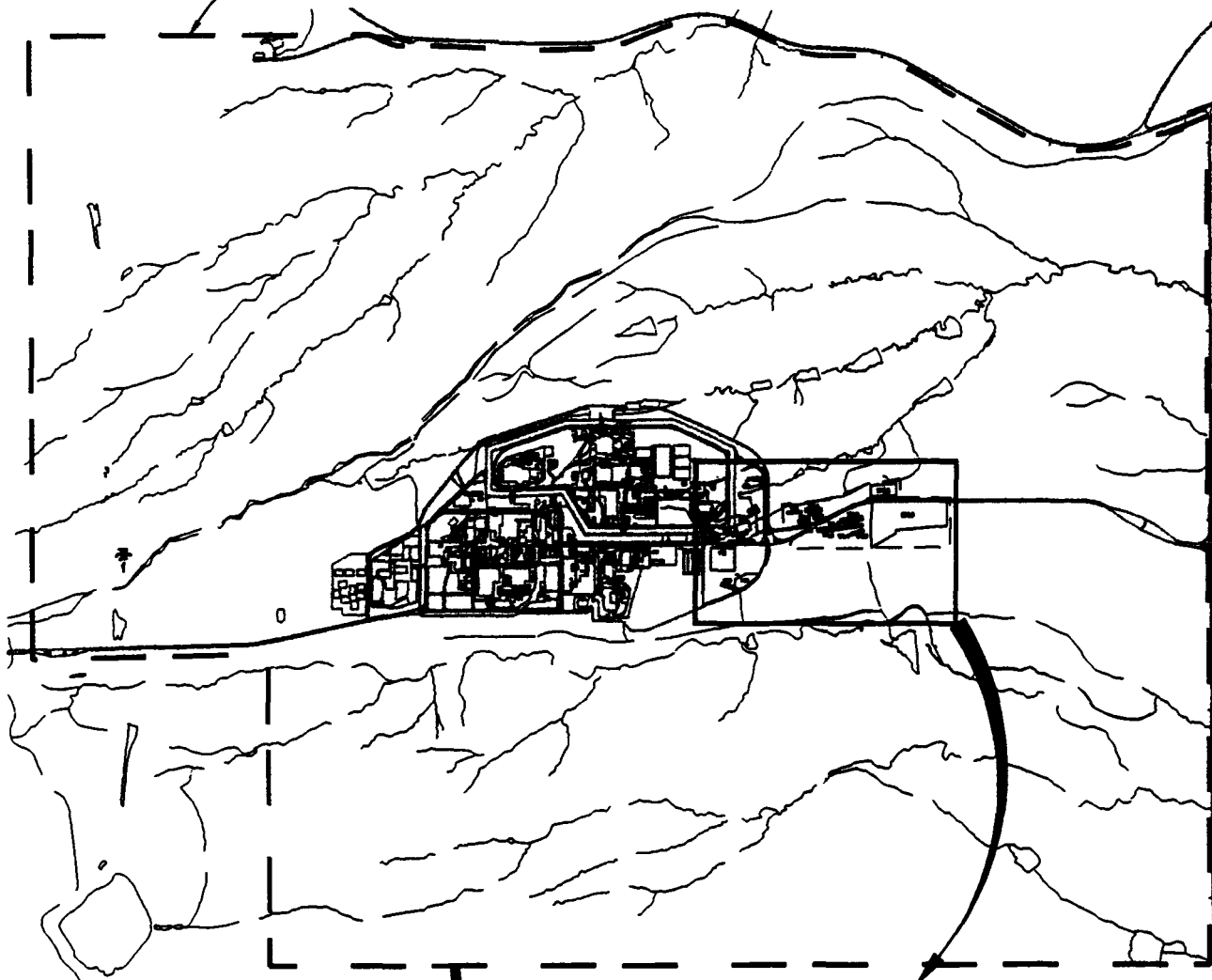
- DOE 1992                      *Historical Releases Report for the Rocky Flats Plant Volume I*  
U S Department of Energy Rocky Flats Plant Golden Colorado  
June 1992
- DOE 1993                      *Phase II RFI/RI Report 903 Pad Mound and East Trenches Area*  
*Operable Unit No 2 Draft* U S Department of Energy Rocky  
Flats Plant Golden Colorado December 1993
- DOE 1994a                    *Development of Remedial Action Objectives 881 Hillside Area*  
*(OU 1) Technical Memorandum No 10 Final* U S Department  
of Energy Rocky Flats Plant Golden Colorado April 1994
- DOE 1994b                    *Technical Memorandum No 9 Chemicals of Concern Human*  
*Health Risk Assessment 903 Pad Mound and East Trenches Areas*  
*Operable Unit No 2 Draft Final* U S Department of Energy  
Rocky Flats Environmental Technology Site Golden Colorado  
August 1994
- DOE 1995a                    *Technical Memorandum No 1 Development of*  
*Corrective/Remedial Action Objectives Operable Unit No 2 Final*  
*Revision 2 (as amended through response to regulator review*  
*comments)* U S Department of Energy Rocky Flats Plant  
Golden Colorado January 1995
- DOE 1995b                    *Alternatives Analysis for Source Remediation at Trench T 3 (IHSS*  
*110) Rocky Flats Environmental Technology Site (Operable Unit*  
*No 2)* U S Department of Energy Rocky Flats Plant Golden  
Colorado April 1995
- EG&G 1991a                    *General Radiochemistry and Routine Analytical Services Protocol*  
*(GRRASP) Part A General Analytical Services Protocol (GASP)*  
*Organics Inorganics Water Quality Parameters Biochemistry*  
*Biota Statement of Work Revision 2* EG&G Rocky Flats  
Environmental Management Department Rocky Flats Plant  
Golden Colorado 1991
- EG&G 1991b                    *General Radiochemistry and Routine Analytical Services Protocol*  
*(GRRASP) Part B Radioanalytical Services Protocol (RASP)*  
*Statement of Work Revision 2 1* EG&G Rocky Flats  
Environmental Management Department Rocky Flats Plant  
Golden Colorado 1991

- EG&G 1994      *Task 3 Report Comprehensive List of Technologies Corrective Measures Study/Feasibility Study* Engineering Science Inc  
January 1994
- EPA 1988      *Guidance for Conducting Remedial Investigations and Feasibility Studies Under CERCLA* OSWER 9355 3 01 U S  
Environmental Protection Agency Office of Emergency and  
Remedial Response Washington D C October 1988
- EPA 1989      *Risk Assessment Guidance for Superfund Volume I Human Health Evaluation Manual (Part A)* EPA/540/1 89/002 U S  
Environmental Protection Agency Office of Emergency and  
Remedial Response Washington D C 1989
- EPA 1992a      *Guidance for Data Useability in Risk Assessment (Part A) Final*  
OSWER 9285 7 09A U S Environmental Protection Agency  
Office of Solid Waste and Emergency Response Washington  
D C 1992
- EPA 1992b      *Considerations in Ground Water Remediation at Superfund Sites and RCRA Facilities* OSWER 9283 1-06 U S Environmental  
Protection Agency Office of Emergency and Remedial Response  
Washington D C May 27 1992
- EPA 1993a      *Guidance for Evaluating the Technical Impracticability of Ground Water Restoration* OSWER 9234 2 25 U S Environmental  
Protection Agency Office of Emergency and Remedial Response  
Washington D C 1993
- EPA 1993b      *Presumptive Remedies Site Characterization and Technology Selection for CERCLA Sites with Volatile Organic Compounds in Soils* OSWER 9355 0-48FS Office of Solid Waste and  
Emergency Response U S Environmental Protection Agency  
Washington D C 1993
- EPA 1994      *Feasibility Study Analysis for CERCLA Sites With Volatile Organic Compounds in Soil* Office of Solid Waste and Emergency  
Response U S Environmental Protection Agency Washington  
D C 1994
- Fedors and Warner 1993      *Characterization of Physical and Hydraulic Properties of Surficial Materials and Groundwater/Surface Water Interaction Study at Rocky Flats Plant* Golden Colorado July 1993

Harnish et al	no date	Particulate Colloidal and Dissolved Phase Associations of Plutonium Americium and Uranium in Water Samples from Well 1587 Surface Water SW 51 and Surface Water SW 53 at the Rocky Flats Plant Colorado
IAG	1991	<i>Rocky Flats Interagency Agreement Between the State of Colorado the Environmental Protection Agency and the Department of Energy</i> 1991
Krey & Hardy	1970	<i>Plutonium in Soil Around the Rocky Flats Plant</i> P W Krey and E P Hardy HASL 235 1970
Litaor	1994	<i>Actinides in the Soil Environment of Operable Unit 2 A Synopsis</i> M Iggy Litaor EG&G Rocky Flats Environmental Restoration Program Department Golden CO
Litaor et al	1994	<i>Heavy Metals in the Environment Plutonium 239+240 and Americium 241 in Soils East of Rocky Flats Colorado</i> Published in J Environ Qual 23 1231 1239 M Iggy Litaor M L Thompson G R Barth and P C Molzer 1994
Litaor et al	unpublished date	<i>Comprehensive Appraisal of Plutonium 239+240 in Soils Around Rocky Flats Colorado</i> M Iggy Litaor D Ellerbroek L Allen Erika Dovala EG&G Rocky Flats Golden CO
Little et al	1980	<i>Plutonium in a Grassland Ecosystem at Rocky Flats</i> Little C A F W Whicker and T F Windsor J Environ Qual 9 350 354 1980
National Research Council	1994	<i>Alternatives for Groundwater Cleanup</i> 1994
Poet and Martell	1972	<i>Plutonium 239 and Americium 241 Contamination in the Denver Area</i> Health Phys 23 537 548 1972
Poulsen et al	1992	<i>A Field Experiment to Study the Behavior of Tetrachloroethylene in Unsaturated Porous Media</i> Environmental Science Technology Volume 25 No 5 1992
Seed et al	1971	Committee Evaluation of Pu Levels in Soils within and surrounding USAEC Installation at Rocky Flats Colorado DOW Chemical Company RFP INV 1

Winsor and Whicker 1979 *Pocket Gophers and Redistribution of Plutonium in Soil* Health  
Physics 28 2189 2195 1979

**ROCKY FLATS ENVIRONMENTAL  
TECHNOLOGY SITE BOUNDARY**

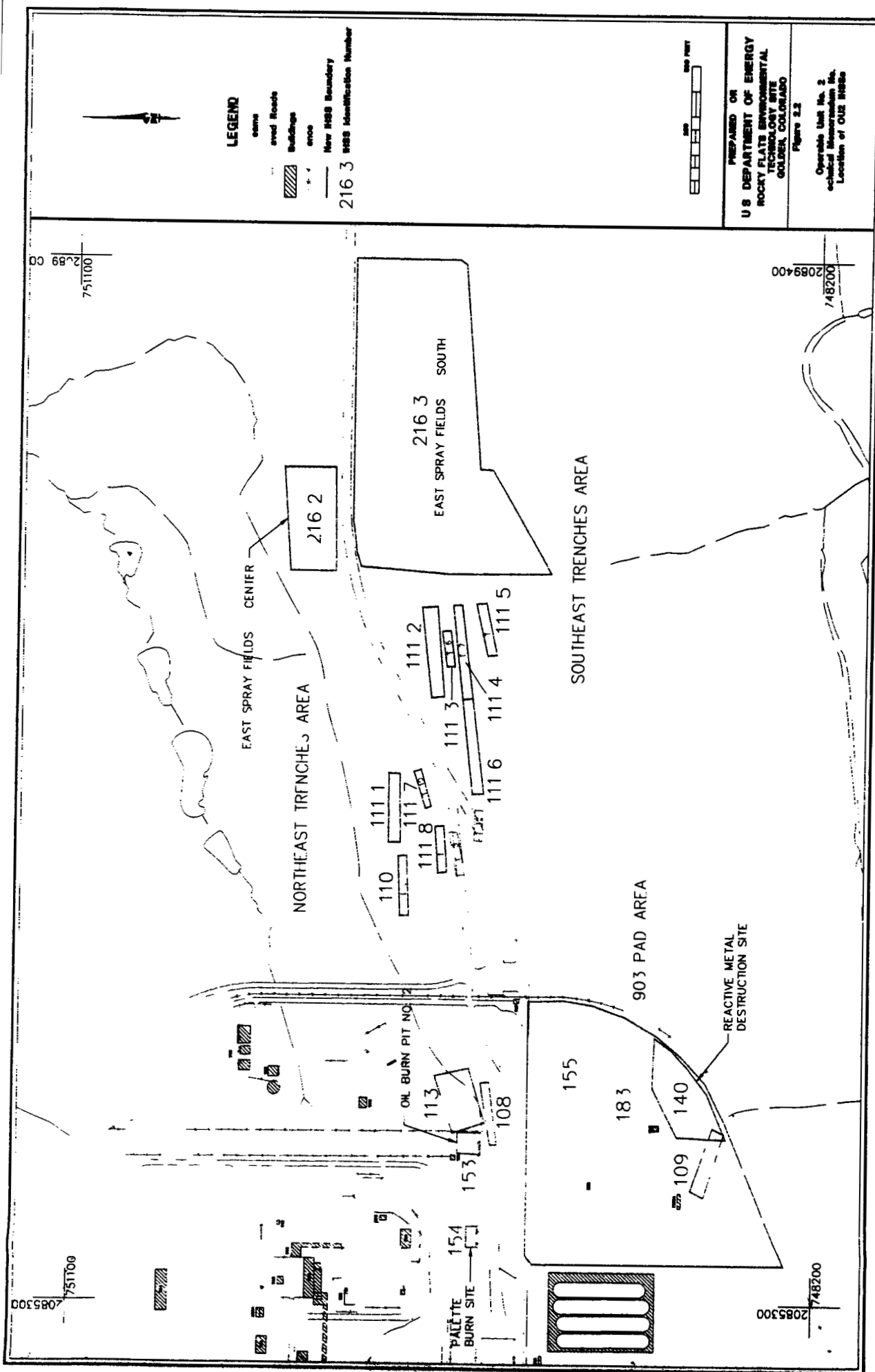


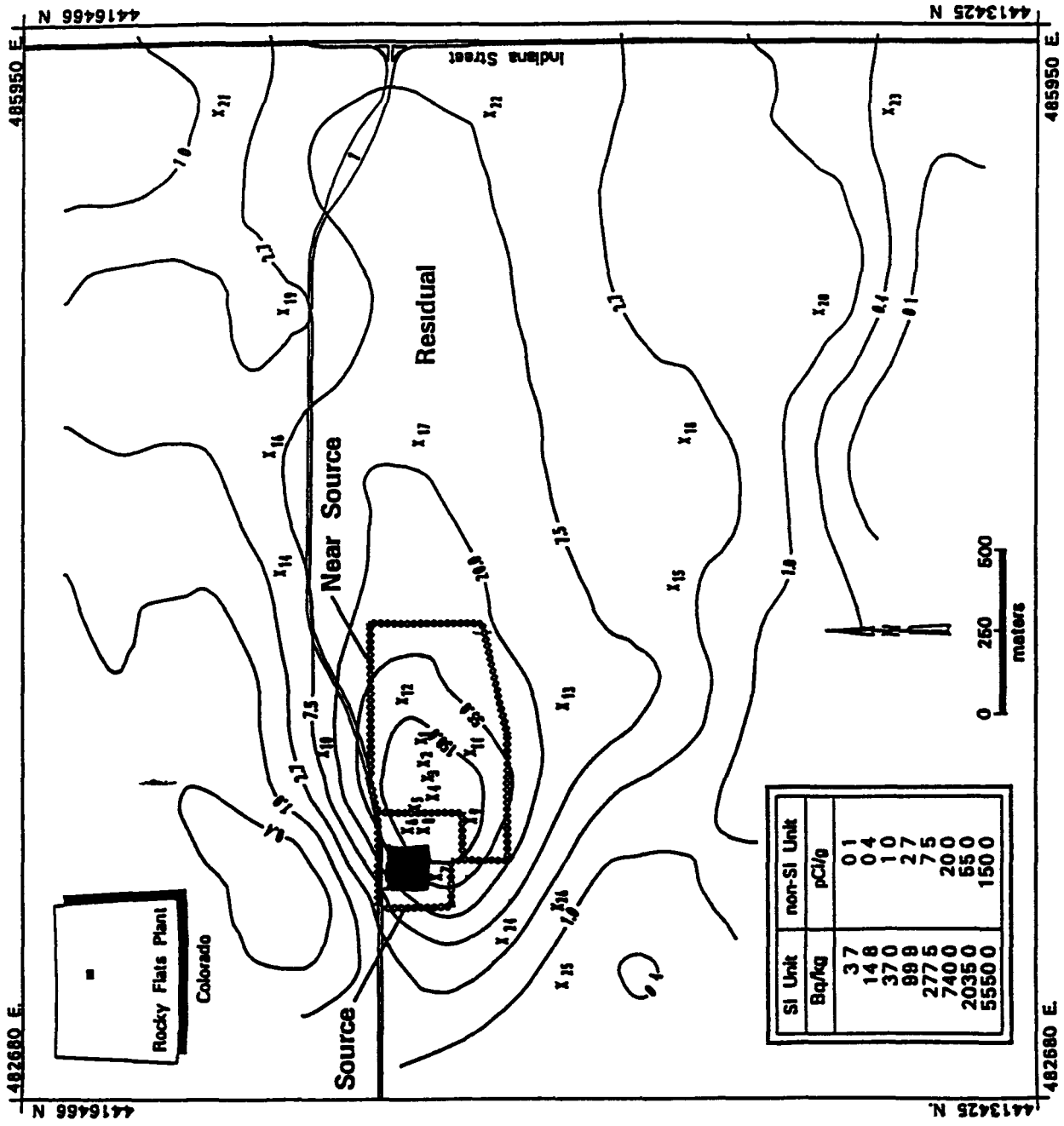
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**Figure 21**

**Operable Unit No 2  
Technical Memorandum No. 2  
Location Map**







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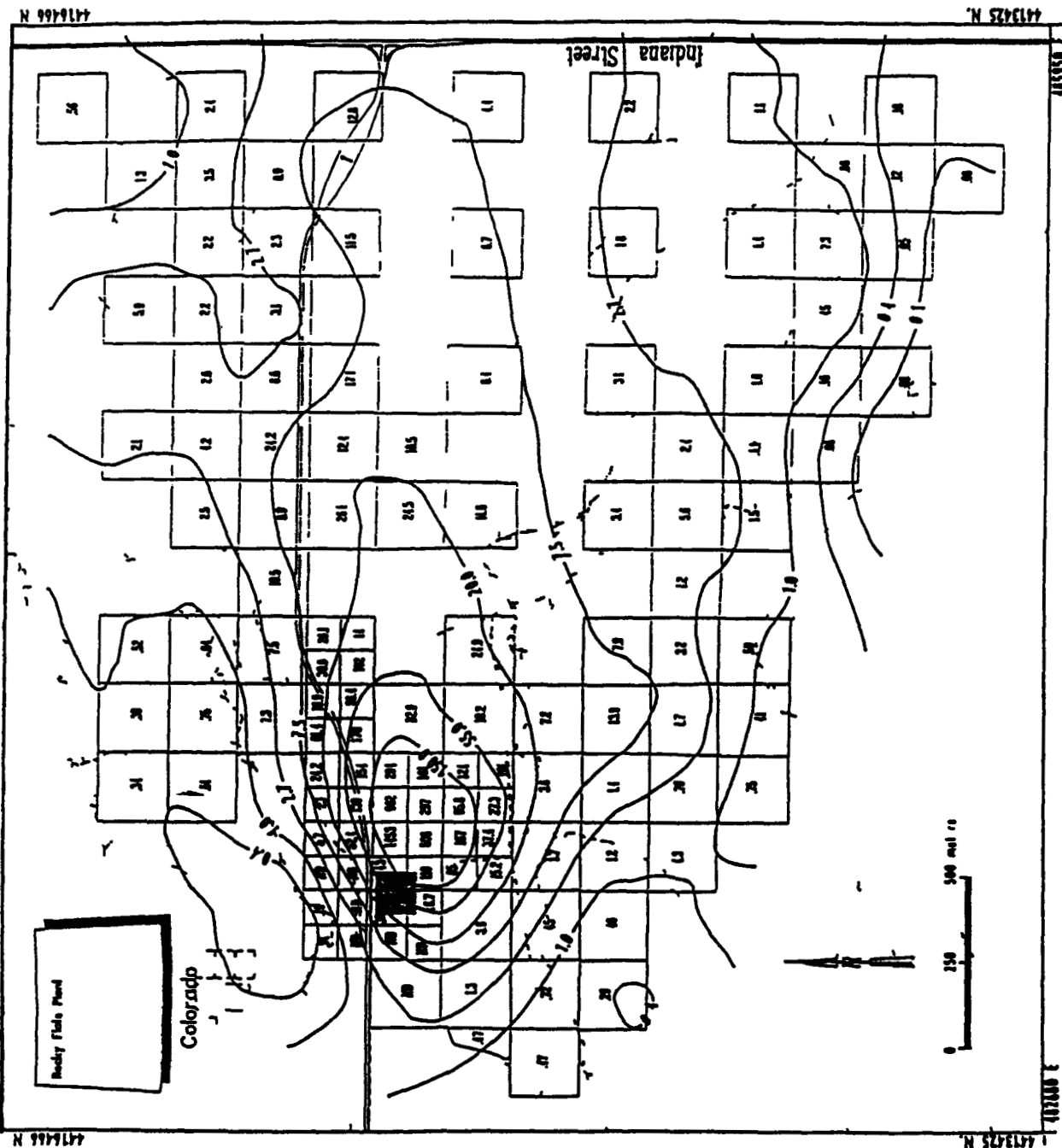
Figure 2.3

Operable Unit No. 2  
 Technical Memorandum No. 2

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Figure 2-4

Operable Unit No. 2  
Technical Memorandum No. 2



# Rocky Flats Surface Soil Sampling Plot Locations Around the 903 Pad

## EXPLANATION

- 903 Pad
- Likens and provide
- Storage facilities
- other
- Storage facilities
- Forces
- Perched roads

Scale: 1 inch = 100 feet  
North arrow pointing up



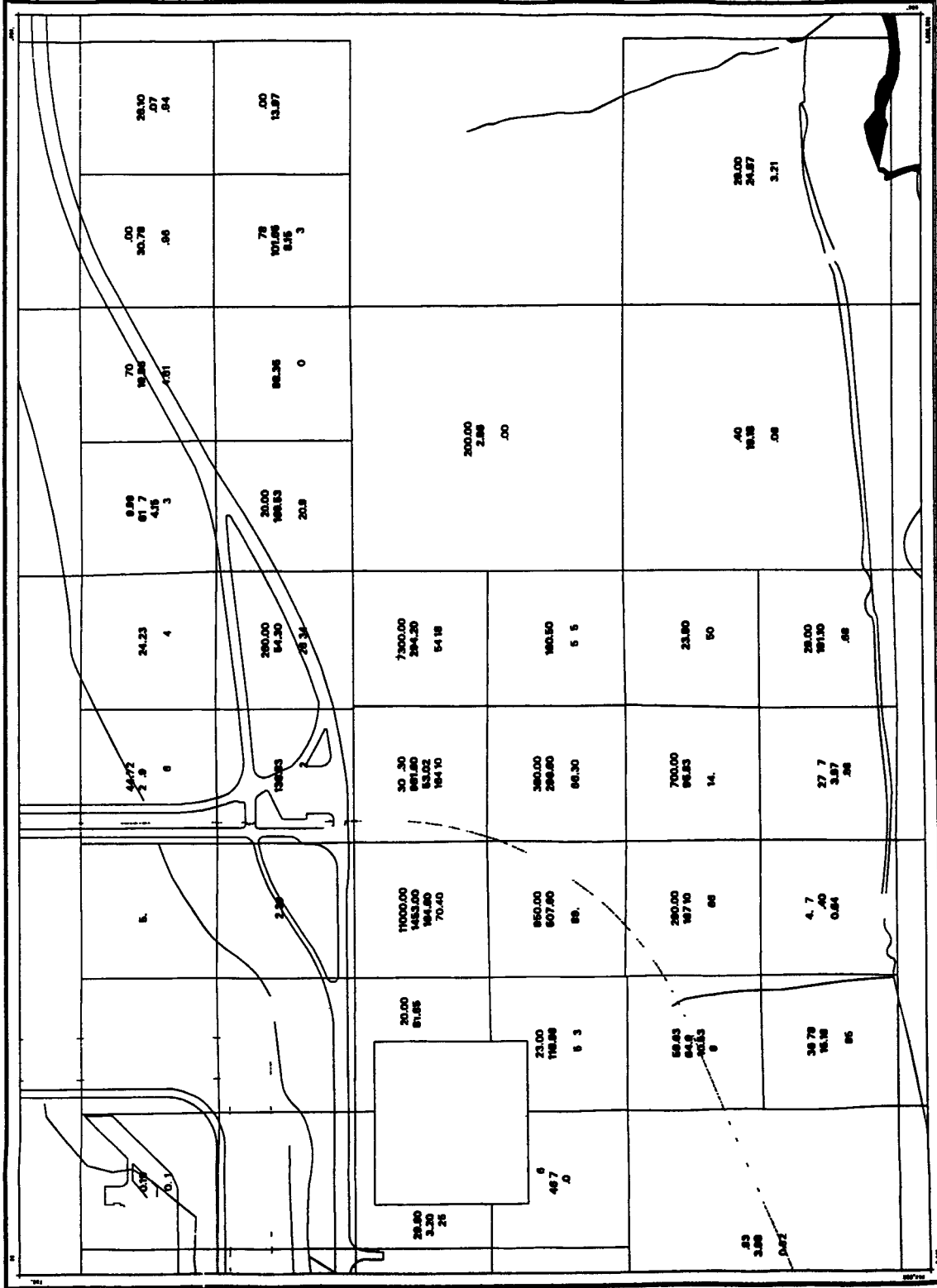
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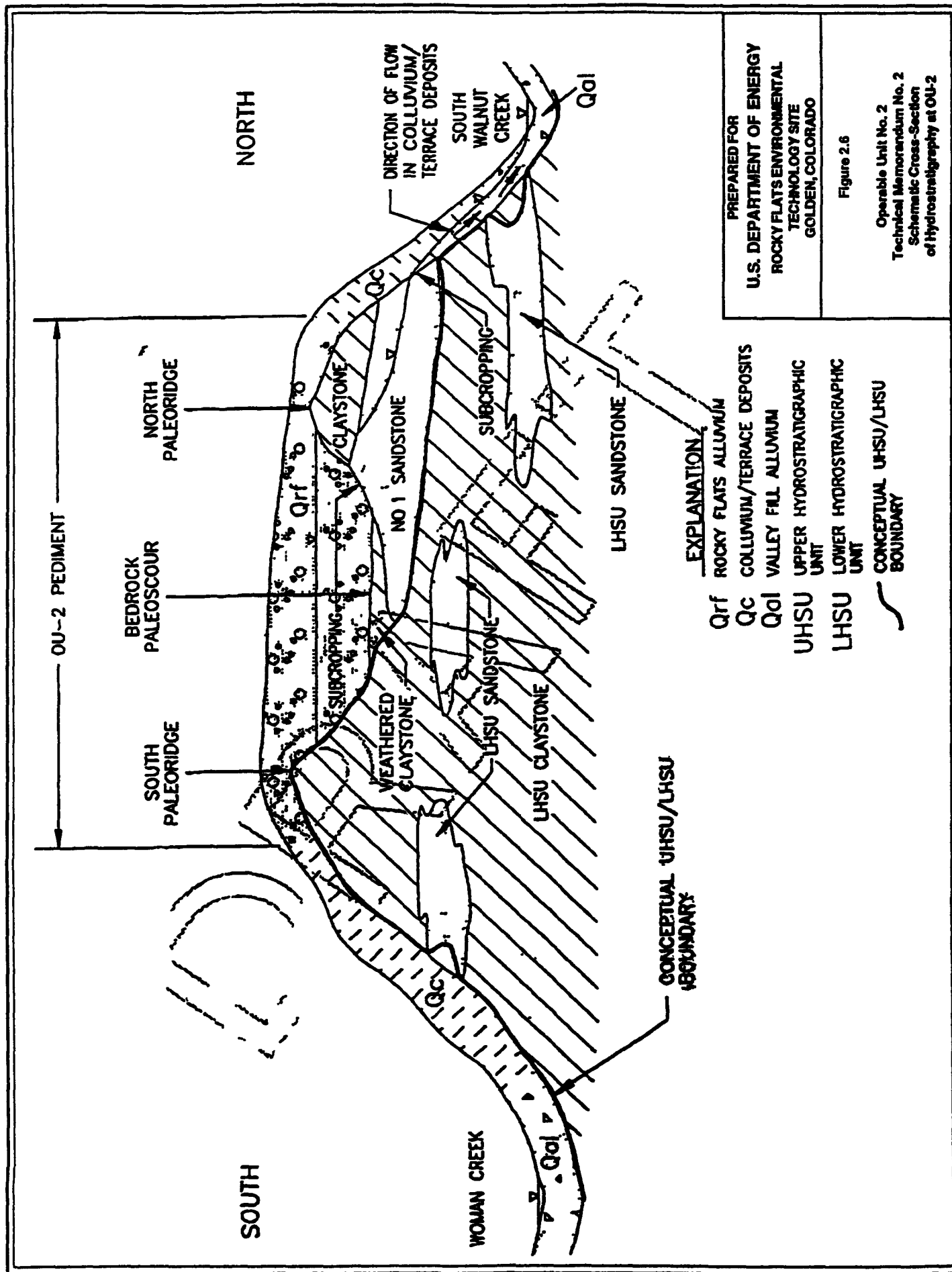
Department of Energy  
Rocky Flats Environmental Technology Site

Prepared by  
Rocky Flats Environmental Technology Site

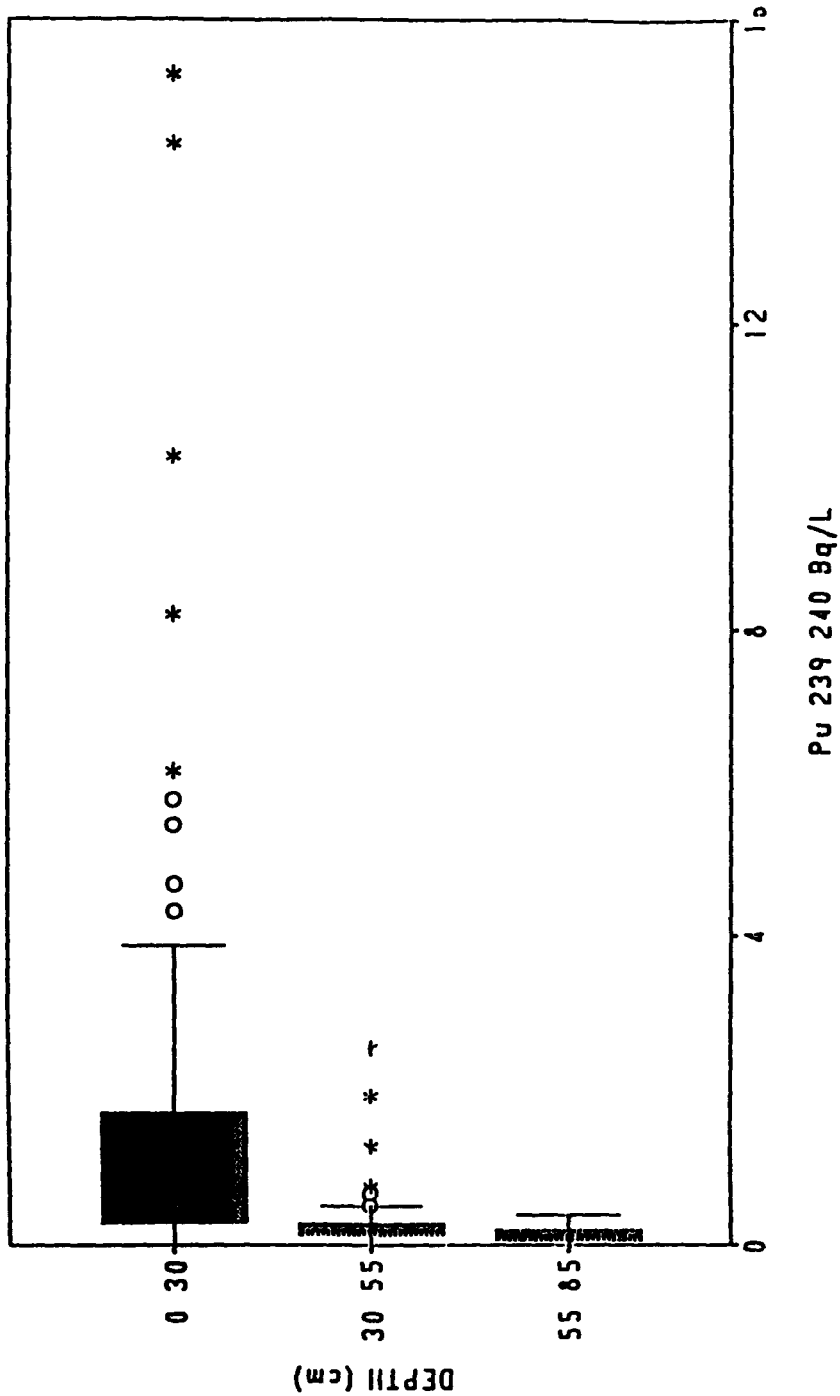
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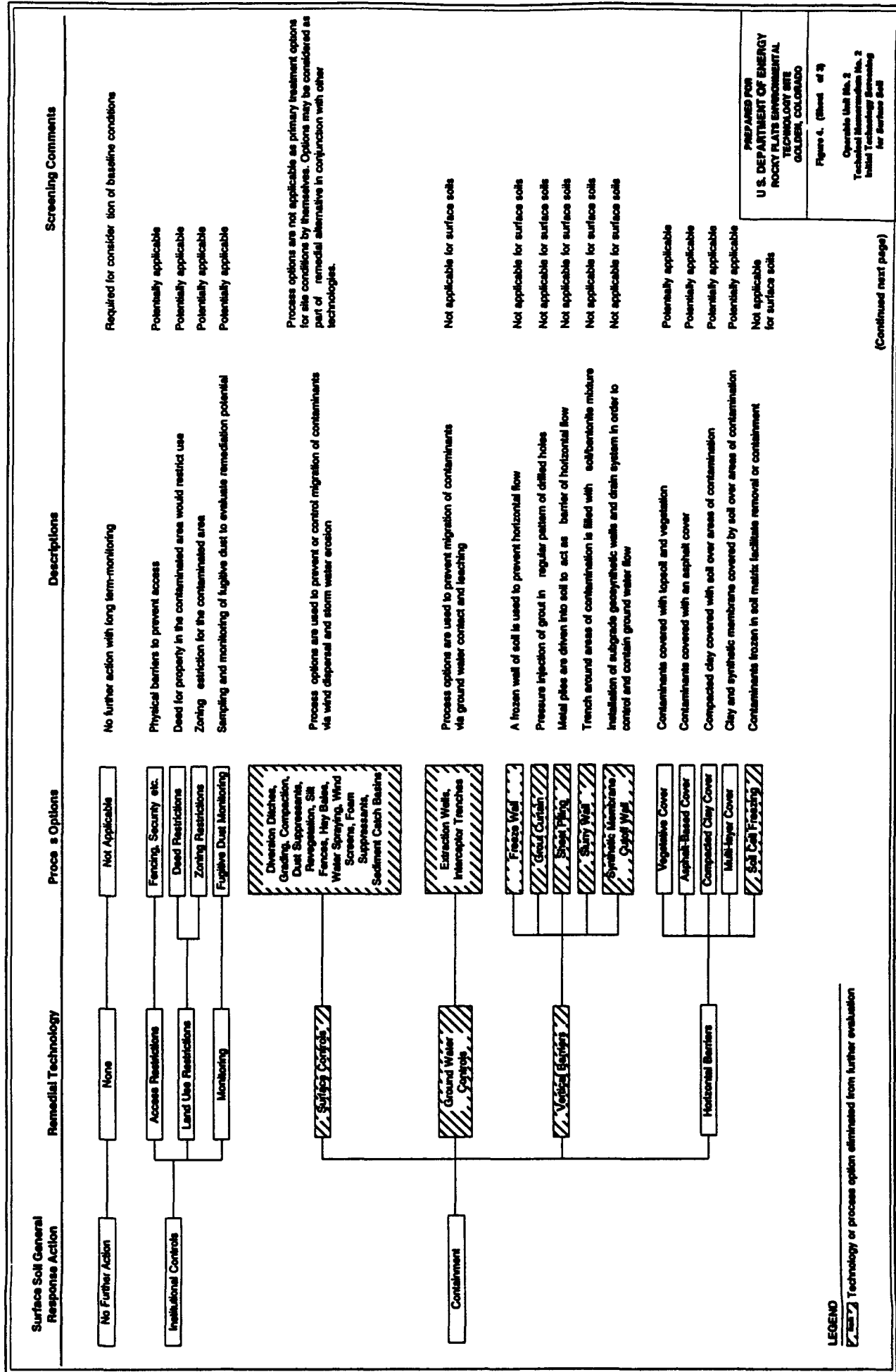




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Figure 2.8

Operable Unit No. 2  
 Technical Memorandum No. 2



Surface Soil General Response Action	Remedial Technology	Process Options	Descriptions	Screening Comments
In situ Treatment	Chemical/Physical	Soil Flushing	Water or water containing an additive leaches contaminants from soil	Not feasible for surface soils
		Freeze/Thawing	Compressed air is used to crack and otherwise open up void spaces in subsoils	Not applicable for surface soils
		Electrokinetic	Ionic species and other charged particles migrate to oppositely charged electrodes in saturated soil mass	Not feasible for surface soils
		Electrokinetic Soil Decontamination	Ionic species and other charged particles migrate to oppositely charged electrodes in saturated soil mass, acoustic field can enhance dewatering and undraining of pores	Not feasible for surface soils
	Solidification/Stabilization	Stabilization, Slurry Injection, Solidification, Cementation, Encapsulation	Process options involve the addition of chemical additive or binder to contaminated soil, with or without soil mixing, reducing mobility and/or toxicity of contaminants	Potentially applicable
Removal	Excavation	Vitrification	Electrodes are used to melt contaminated soils producing glass monolith	Not feasible for surface soils
		Soil Excavation	Removal or consolidation of surface soils using earth moving equipment	Potentially applicable
	Short Distance Transport	Conveyor System	Conveyor system to transport contaminants from removal to on-site treatment, storage, or disposal (TSD) facility	Potentially applicable
		Slurry Pipeline	Slurry is pumped to on-site TSD facility	Potentially applicable
	Long Distance Transport	Truck/Rail Hauling	Transportation of contaminated material by truck or rail	Potentially applicable
		Landfill/TSD Facility	Contaminated material is removed and transported to permitted off-site TSD facility	Potentially applicable
	Off-site Storage/Disposal	Disposal Vault	Disposal of waste materials in on-site disposal vault	Potentially applicable
		Container Storage	Contaminated material is temporarily or permanently stored on-site in drums or containers	Potentially applicable
	On-site Storage/Disposal	Permitted Landfill	Disposal of waste materials in newly constructed on-site landfill	Potentially applicable
		Spreading and/or Backfilling	Disposal of waste materials by spreading and/or backfilling across wide areas on-site	Not applicable as primary option. May be considered as part of remedial alternative

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Figure 4, (Sheet 2 of 3)

Operable Unit No. 2  
Technical Memorandum No. 2  
Initial Technology Screening  
for Surface Soil

#### LEGEND

 Technology or process option eliminated from further evaluation

A TSD facility is defined here to be any nonhazardous, hazardous, radioactive, or mixed waste permitted facility that provides treatment, storage and/or disposal.

(Continued next page)

Surface Soil General Response Action	Remedial Technology	Process Options	Descriptions	Screening Comments
		<div> <div>Chemical/Physical</div> <div> <div>Chemical Red/Ox (1)</div> <div>Sol W string (2)</div> <div>Solvent Extraction (3)</div> <div>Electrokinetics</div> <div>Physical Separation (4)</div> <div>Magnetic Separation (5)</div> </div> <div>Biological</div> <div>Biological Leaching (6)</div> </div>	<p>Oxidation state of contaminants is altered or lowered to achieve less toxic, less mobile, or more disposable form</p> <p>Contaminants sorbed onto soil particles are separated from soil in an aqueous-based system</p> <p>Solvent leaches contaminants from feed - e.g. acid leaching</p> <p>Ionic species and other charged particles migrate to oppositely charged electrodes in saturated soil</p> <p>Volume of soil contaminants reduced by separating particular size fraction of the soil or liquid removal from soils</p> <p>Separation and concentration of particles according to magnetic susceptibility</p> <p>Microbes used to enhance solubility of contaminants</p>	<p>Potentially applicable</p> <p>Potentially applicable</p> <p>Not proven for Pu removal in soils</p> <p>Potentially applicable</p> <p>Potentially applicable</p> <p>Potentially applicable</p> <p>Potentially applicable</p> <p>Potentially applicable</p>
		<div> <div>Solidification/Stabilization</div> <div> <div>Stabilization (7)</div> <div>Encapsulation</div> <div>Cementation</div> <div>           Verification:            (Plasma Arc, Slagging Furnace, Joule-Heated, Glass Melter)         </div> </div> </div>	<p>Addition of chemical reagent to react with the contaminants, producing less mobile or less toxic compound</p> <p>Complete coating or encasement of toxic waste agglomerates with new substance</p> <p>Contaminants are physically bound within solidified mass, reducing mobility and/or toxicity of contaminants</p>	<p>Potentially applicable</p> <p>Potentially applicable</p> <p>Potentially applicable</p> <p>Potentially applicable</p> <p>Potentially applicable</p>
		<div> <div>Thermal</div> <div> <div>Incineration:                (Fluidized Bed, Infrared, Molten Salt, Multiple-Hearth, Microwave Melting, Molten Metal Reactor, Rotary Kiln, Oxygen-Enhanced, Liquid Injection)             </div> </div> </div>	<p>Organic contaminants react to form innocuous products, solids and metals are vitrified into glass or vitrified slag product</p> <p>Thermal destruction of contaminants and soil matrix</p>	<p>Not feasible for Pu in low organic soil</p>
		<div> <div>Thermal</div> <div> <div>Pyrolysis</div> </div> </div>	<p>Organic contaminants are decomposed by heat in the absence of oxygen, reducing total volume of contaminants</p>	<p>Not feasible for Pu in low organic soil</p>

# LEGEND

Technology or process option eliminated from further evaluation

NOTE: Process options are components of the following treatment systems or studies:

- (1) Aqueous Biphasic Separation (ABS)

(2) TRU Clean®

Chemically Enhanced Steam Stripping (CESS)

Chelating Agents (JNL Study)

Gravity/Filtration/Chemical Enhancement (NRT Study)

(3) CEPOD Process (PHL)

B.E.S.T. Process
- (4) Aqueous Biphasic Separation (ABS)

Air Sparged Hydrocyclone (ASH)

TRU Clean®

Gravity/Filtration/Chemical Enhancement (NRT Study)

(5) High Gradient Magnetic Separation (HGMS)

(6) MBX Study (Lockheed)

(7) WES-PHX Process

Can be used as component of soil washing process

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Initial Technology Screening  
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Subsurface Soil General Response Action	Remedial Technology	Process Options	Descriptions	Screening Comments
No Further Action	None	Not Applicable	No further action with long-term monitoring	Required for consideration of baseline conditions
Institutional Controls	Access Restrictions	Fencing, Security, etc.	Physical barriers to prevent access	Potentially applicable
	Land Use Restrictions	Deed Restrictions	Deed for property in the contaminated area would restrict use	Potentially applicable
	Monitoring	Zoning Restrictions	Zoning restriction for the contaminated area	Potentially applicable
		Ground Water Monitoring	Sampling and monitoring of ground water to evaluate remediation performance	Potentially applicable
		Vadose Zone Monitoring	Sampling and monitoring of vadose zone to evaluate remediation performance	Potentially applicable
Containment	Surface Controls	<div> <div>Diversion Ditches, Grading, Compaction, Dust Suppressants, Revegetation, Silt Fences, Hay Bales, Water Spraying, Wind Screens, Foam Suppressants, Sediment Catch Basins</div> </div>	Process options are used to prevent or control migration of contaminants via wind dispersal and storm water erosion	Process options are not applicable as primary treatment options for site conditions by themselves. Options may be considered as part of remedial alternative in conjunction with other technologies such as horizontal barriers and excavation
	Ground Water Controls	<div> <div>Extraction Wells, Interceptor Trenches</div> </div>	Process options are used to prevent migration of contaminants via ground water contact and leaching	Process options are not applicable as primary treatment options for site conditions by themselves. Options may be considered as part of remedial alternative in conjunction with other technologies such as horizontal barriers and excavation
	Vertical Barriers	Freeze Wall	A frozen wall of soil is used to prevent horizontal flow	Not practical for long-term immobilization
		Grout Curtain	Pressure injection of grout in regular pattern of drilled holes	Eliminated incapable of attaining truly low permeabilities in unconsolidated materials
		Steel Piling	Metal piles are driven into soil to act as barrier to horizontal flow	Eliminated, wall integrity at the joints is extremely difficult or impossible to control
		Slurry Wall	Trench around areas of contamination is filled with soil/bentonite mixture	Potentially applicable
Horizontal Barriers		Synthetic Membrane Cutoff Wall	Installation of subsurface geosynthetic walls and drain system in order to control and contain ground water flow	Potentially applicable
		Vegetative Cover	Top soil (6") layer seeded.	Potentially applicable
		Asphalt-based Cover	Contaminants covered with an asphalt cover	Potentially applicable
		Compacted Clay Cover	Compacted clay covered with soil over areas of contamination	Potentially applicable
		Multi-layer Cover	Clay and synthetic membrane covered by soil over areas of contamination	Potentially applicable
		Soil Cell Freezing	Contaminants frozen in soil matrix facilitate removal or containment	Not practical for long-term immobilization


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LEGEND  
Technology or process option eliminated from further evaluation

(Continued next page)

Subsurface Soil General Response Action	Remedial Technology	Process Options	Descriptions	Screening Comment
In situ Treatment	Biological	Bioremediation	Oxygen is delivered at low flow rates to contaminated unsaturated soils by forced air to increase oxygen concentrations and stimulate biodegradation	Not feasible for leachates (i.e. chlorinated solvents)
		Enhanced Bioremediation	Microbes with or without oxygen, methane, other gases, or an aromatic carbon can induce degradation and/or co-metabolism of organics	Potentially applicable
	Chemical/Physical	Soil Flushing	Water or water containing an additive leaches contaminants from soil	Eliminated, due to association with contaminating ground water with DNAPLs
		Surfactant-Enhanced Desorption	Injection of surfactant into contaminated soil to enhance desorption of non-aqueous-phase liquids. Soil flushing technique when used in situ	Eliminated due to risk associated with contaminating ground water with DNAPLs
		Pneumatic Fracturing	Compressed air is used to crack and otherwise open up void spaces in sub-soils	Potentially applicable
		Soil Gas Venting	Passive venting of soil gases to control gas migration using high and low permeability materials, vent trenches, and vent wells	Potentially applicable
		Soil Vapor Extraction	Vacuum is applied through extraction wells or trenches to create pressure gradient that induces gas-phase volatiles to diffuse through soil to extraction wells	Potentially applicable
		Electrokinetics	Ionic species and other charged particles migrate to oppositely charged electrodes in saturated soil mass	Potentially applicable
		Electroacoustic Soil Decontamination	Ionic species and other charged particles migrate to oppositely charged electrodes in saturated soil mass, acoustic field can enhance dewatering and undrugging of pores	Potentially applicable
	Solidification/Stabilization	Stabilization	Process options involve the addition of chemical reagent to react with the contaminants producing less mobile or less toxic compound	Potentially applicable
		Slurry Injection Solidification	A grout is injected into the soil where it hardens and immobilizes any contaminants	Eliminated, impossible to control process in unconsolidated materials
		Cementation	Soil mixing techniques and pozzolanic agents are used to produce solidified soil mass	Potentially applicable
	Thermal	Encapsulation	A process involving the complete coating or enclosure of toxic waste agglomerates with new substance, e.g., epoxies and polyesters	Eliminated difficult to control process in unconsolidated materials
		Vitrification	Electrodes are used to melt contaminated soils producing glass monolith	Potentially applicable
		T SVE	Soils are heated to increase the mobility of volatiles and facilitate extraction. Vacuum is applied to create pressure gradient that induces gas-phase volatiles to diffuse through soil to extraction wells while heat source is applied.	Potentially applicable

**LEGEND**  
 Technology or process option eliminated from further evaluation  
 A TSD facility is defined here to be any nonhazardous, hazardous, radioactive or mixed waste permitted facility that provides treatment, storage and/or disposal.

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Figure 4.2 (Sheet 2 of 4)  
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 Initial Technology Screening  
 for Subsurface Soil

(Continued on next page)

Subsurface Soil General Response Action	Remedial Technology	Process Options	Descriptions	Screening Comments
Removal	Excavation	Soil Excavation	Removal or consolidation of soils using earth moving equipment	Potentially applicable
	Short Distance Transport	Conveyor System	Conveyor system to transport contaminants from removal to treatment, storage or disposal (TSD) facility	Potentially applicable
	Long Distance Transport	Truck Hauling	Transportation of contaminated material by truck	Potentially applicable
	Offsite Storage/Disposal	Truck/Rail Hauling	Transportation of contaminated material by truck or rail	Potentially applicable
	Onsite Storage/Disposal	Landfill/TSD Facility	Contaminated material is removed and transported to permitted offsite TSD facility	Potentially applicable
Ex situ Treatment	Chemical/Physical	Disposal Vault	Disposal of waste materials in onsite disposal vault	Potentially applicable
		Container Storage	Contaminated material is temporarily or permanently stored onsite in portable containers	Potentially applicable
		Permitted Landfill	Disposal of waste materials in newly constructed onsite landfill	Potentially applicable
		Spreading/Backfilling	Disposal of waste materials by spreading and/or backfilling across wide areas onsite	Not feasible for site contaminants
		Controlled Solid Phase Treatment Composting	Soils are mixed with soil amendments and placed in aboveground enclosures that have leachate collection systems and some form of aeration. Moisture, heat, nutrients, oxygen, and pH may be controlled to enhance biodegradation	Eliminated, not practical with the projected volumes of contaminated soils
Ex situ Treatment	Chemical/Physical	Landfarming	Contaminated soils are applied onto the soil surface and periodically turned over or tilled into the soil to aerate the waste	Eliminated, not applicable for radiologically contaminated soils
		Sunry Phase Treatment	An aqueous slurry is created by combining soil or sludge with water and other additives. Nutrients are controlled to enhance biodegradation	Eliminated, not practical with the projected volumes of contaminated soils
		Chemical Red/Ox (1)	Oxidation state of contaminants is raised or lowered to achieve less toxic, less mobile or more deposable form	Potentially applicable based on work at INEL
		Soil Washing (2)	Contaminants sorbed onto soil particles are separated from soil in an aqueous-based system	Potentially applicable
		Solvent Extraction (3)	Solvent leaches contaminants from feed, e.g. Acid Leaching	Potentially applicable
		Dehalogenation	An alkaline polyethylene glycolate or base is used to dehalogenate halogenated aromatic compounds in batch reactor	Potentially applicable
		Hydrolysis	Hydrolysis is the use of water to destroy decompose, or alter chemical species that might ignite, explode, or produce toxic gases; it is also applicable to corrosive wastes	Potentially applicable
		Soil Vapor Extraction	A vacuum is applied to network of aboveground piping to encourage volatilization of organics from the excavated media	Eliminated, not applicable for site contaminants
		Electrokinetics	Ionic species and other charged particles will migrate to oppositely charged electrodes in saturated soil	Potentially applicable
		Physical Separation (4)	Volume of soil contaminants reduced by separating particular size fraction of the soil	Potentially applicable
		Magnetic Separation (5)	Separation and concentration of particles according to magnetic susceptibility	Potentially applicable

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Figure 2 (Sheet of 4)  
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LEGEND  
Technology or process option eliminated from further evaluation  
Can be applied with soil washing

(Continued next page)

Subsurface Soil General Response Action	Remedial Technology	Process Options	Descriptions	Screening Comments
<div>Ex situ Treatment</div>	Solidification/Stabilization	Stabilization (6)	Process that involves the addition of chemical reagent to each with the contaminants, producing less mobile or less toxic compound	Potentially applicable
		Encapsulation	A process involving the complete coating or enclosure of toxic waste agglomerate with new substance, e.g., epoxies and polyesters	Potentially applicable
		Cementation	Contaminants are physically bound within solidified mass	Potentially applicable
		Vitrification: (Plasma Arc, Slagging Furnace, Joule-Heated, Glass Melter)	Organic contaminants react to form innocuous products and metals are vitrified into glass or vitrified slag product	Potentially applicable
	Thermal	Incineration: (Fluidized Bed/Unfired, Molten Salt, Solar Multiple-Heater, Microwave Melting, Molten metal reactor, Rotary Kiln, Oxygen-Enhanced, Liquid Injection, High Temperature Fluid Wall)	Thermal destruction of organic contaminants in soils, reducing total volume of contaminants	Potentially applicable
		High-Temperature Thermal Desorption	Wastes are heated to 600-1000°F to volatilize water and organic contaminants	Eliminated low-temperature thermal desorption process for VOC
		Low-Temperature Thermal Desorption	Wastes are heated to 200-600°F to volatilize water and organic contaminants	Potentially applicable
		HTS Thermal Distillation Process	Soils are heated in nitrogen atmosphere to volatilize VOCs and SVOCs	Potentially applicable
		Supercritical Water Oxidation, Wet Air Oxidation	Organics are oxidized in water mixture	Not directly applicable for unsaturated soils. Options may be considered as part of remedial alternatives in which soils are treated as part of an aqueous process.
		Pyrolysis	Organics decomposed by heat in the absence of oxygen	Potentially applicable

LEGEND

Technology or process option eliminated from further evaluation

NOTE: Process options are components of the following treatment systems or studies:

- (1) Aqueous Biphasic Separation (ABS)  
 (2) TRU Clean®  
   Surfactant Enhanced Remediation  
   Aqueous Biphasic Separation  
   Chemically Enhanced Steam Stripping (CESS)  
   Chelating Agents (LANL Study)  
   Gravity/Floation/Chemical Enhancement (NRT Study)  
 (3) CEPOD Process (PWL)  
   B E S T Process
- (4) Aqueous Biphasic Separation (ABS)  
   Surfactant Enhanced Remediation  
   Air Sparged Hydrocyclohexane (ASH)  
   TRU Clean®  
   Gravity/Floation/Chemical Enhancement (NRT Study)  
 (5) High Gradient Magnetic Separation (HGMS)  
 (6) WES-PHX Process

Groundwater General Response Action	Remedial Technology	Process Option	Descriptions	Screening Comments
No Further Action	Intrinsic Remediation	Groundwater Monitoring	No further action with long-term sampling analysis and monitoring to evaluate intrinsic remediation	Required for consideration of baseline conditions
Institutional Controls	Access Restrictions	Fencing, Security	Physical barriers to prevent access	Potentially applicable
		Lock Out/Tag Out Wells	Physical barriers to prevent access	Potentially applicable
		Deed Restrictions	Deed modifications on property in the contaminated area would restrict use	Potentially applicable
		Zoning Restrictions	Zoning restriction for the contaminated area	Potentially applicable
Institutional Controls	Land Use Restrictions	Regulatory Restrictions	Local regulation prohibiting installation of water well in contaminated area	Potentially applicable
		Regulatory Restrictions	Long-term sampling, analysis and monitoring of groundwater to evaluate intrinsic remediation	Potentially applicable
		Regulatory Restrictions	Process options used to enhance surface water runoff and maximize evapotranspiration and to minimize infiltration and percolation of water and contaminant leaching to groundwater	Potentially applicable
		Regulatory Restrictions	Processes that intercept and extract contaminated groundwater	Potentially applicable
Containment	Surface Water Controls	Enhanced Soil Treatment, Revegetation, Grading, and Compaction	A frozen wall of soil is used to prevent horizontal flow	Eliminated; not long-term solution
		Interceptor Trenches and Local Extraction Wells	Subsurface barrier created by high pressure injection of grout into unconsolidated material or bedrock fractures	Eliminated; incapable of treating low permeabilities in unconsolidated materials
		Freeze Wall	Installation of subsurface sheet pile wall as groundwater barrier	Potentially applicable
		Grout Curtain	Installation of low-permeability, subgrade slurry wall for groundwater control	Potentially applicable
	Vertical Barriers	Sheet Piling	Installation of subgrade HDPE wells and drain system to contain groundwater	Potentially applicable
		Slurry Wall	An asphalt-type cover over contaminated areas to enhance surface water runoff and reduce water percolation and leaching of contaminants to groundwater	Potentially applicable
		Synthetic Membrane Cutoff Wall	A compacted clay cover over contaminated areas to enhance surface water runoff and reduce water percolation and leaching of contaminants to groundwater	Potentially applicable
		Asphalt-Type Cover	Compacted clay and/or geosynthetic cover over contaminated areas to enhance surface water runoff and reduce water percolation and leaching of contaminants to groundwater	Potentially applicable
	Horizontal Barriers	Compacted Clay Cover	Contaminants frozen in soil matrix prevent percolation and leaching of contaminants to groundwater	Eliminated; not long-term solution
		Multi-Layer Cover	Processes that intercept and extract contaminated groundwater	Potentially applicable
		Soil Cell Freezing	Processes that are used to transport contaminated groundwater	Potentially applicable
		Interceptor Trenches and Local Extraction Wells	Processes options that are used to dispose contaminated groundwater	Eliminated; off-site facilities can not treat radionuclides
Removal	Groundwater Extraction	Truck/Trail Hauling Pipelines	Transport to RFETS sewage treatment plant for disposal	Potentially applicable
		Disposal	Process options for the permanent or temporary storage of untreated groundwater	Eliminated; not long-term solution
		RFETS STP		
		Storage Tanks, Drum Storage		

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Figure 4.3 (Sheet 1 of 4)

Operator Unit No. 2  
Technical Memorandum No.  
Initial Technology Screening  
for Groundwater

(Continued next page)

# LEGEND

Technology or process option eliminated from further evaluation

Groundwater General Response Action	Remedial Technology	Process Options	Descriptions	Screening Comments
In Situ Treatment	Enhanced Bioremediation	Enhancement of aerobic or anaerobic conditions, cometsabolic substrates	Injection of oxygen, nutrients, electron acceptors into groundwater to enhance the degradation and/or cometabolism of organics	Potentially applicable
		Hydraulic Fracturing	Water and/or slurried sand is forced at high pressure into contaminated zone, creating pathways and fractures to enhance groundwater flow in the subsurface	Eliminated: presence of DNAPLs at site requires detailed understanding and control of fracture/pathway orientation
		Precipitation, Redox	Injection of chemical into contaminated groundwater to reduce and precipitate redoxsensitive	Eliminated: not long-term solution
		Surfactant-Enhanced Desorption (1)	Injection of surfactant into contaminated groundwater to enhance desorption of nonaqueous-phase liquids (NAPLs)	Eliminated; difficult to control desorbed DNAPL movement
	Chemical/Physical	Air Sparging	Injection of air into groundwater to remove volatile organic compounds	Potentially applicable
		Free Product Recovery	Undissolved NAPLs are extracted from subsurface	Eliminated: part of source removal under EECa
		Absorption, Adsorption	See Passive Treatment Wall	Eliminated: component of passive treatment wall
		Passive Treatment Wall	Construction of in situ treatment wall to degrade, sorb, exchange or precipitate volatile organic compounds and radionuclides in contaminated groundwater	Potentially applicable
		Electrokinetic	Groundwater flow toward extraction well is accelerated with the use of direct current applied to electrodes placed in the contamination plume	Eliminated; difficult to implement
		Ion-Exchange	See Passive Treatment Wall	Eliminated: component of passive treatment wall
Groundwater Extraction	Solidification/Stabilization	Contaminants, Soil Mix Wall, Soil Mixing	Aquifer materials are mixed with cementitious materials to form solidified matrix	Eliminated: maybe potentially applicable as vertical barrier but not as standalone groundwater treatment
	Thermal	Steam Sparging T SVE	Steam is forced into an aquifer through injection wells to vaporize VOC and SVOC contaminants.  Saturated zone is heated to increase the mobility of volatiles. Vacuum applied to create pressure gradient that induces gas-phase volatiles to diffuse through soil to extraction wells.	Eliminated; difficult to hydraulically control process  Potentially applicable for organics








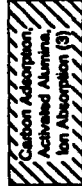





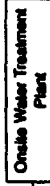

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Initial Technology Screening  
for Groundwater


LEGEND

Technology or process option eliminated from further evaluation

(Continued next page)

Groundwater General Response Action	Remedial Technology	Process Options	Descriptions	Screening Comments
 Ex Situ Treatment	 Bioremediation	 Anaerobic White-Rot Fungus, Methanotropic, Trickling Filter Fixed Film, Combined Treatment, Rotating Biological Contactors, Activated Sludge, Lagoons/Ponds	Microbes with or without oxygen, methane, other gases or an aromatic compound can induce degradation and/or cometabolism of dissolved organic compounds in groundwater	Eliminated; groundwater will be treated at onsite water treatment plant
		 Wetlands-Based Treatment	Constructed wetlands use natural geochemical and biological processes to accumulate and remove metals and radionuclides, and to degrade organics in influent groundwater. Provides both aerobic and anaerobic conditions	Eliminated; groundwater will be treated at onsite water treatment plant
		 Biological Sorption (2)	Algae or other biomass (e.g., sphagnum peat moss) is used to remove heavy metals or radionuclides from groundwater	Eliminated; groundwater will be treated at onsite water treatment plant
	 Chemical/Physical	 Sedimentation, Gravity Separation, Centrifugation	Particles and/or different liquid phases are separated by the use of gravity	Eliminated; groundwater will be treated at onsite water treatment plant
		 Carbon Adsorption, Activated Alumina, Ion Absorption (3)	Adsorption of contaminants onto an adsorbent (activated carbon, ion coated sand) by passing contaminated groundwater through packed column	Eliminated; groundwater will be treated at onsite water treatment plant
		 Coagulation/ Flocculation, Electrocoagulation (4)	Introduction of chemicals or electrically charged species to contaminated groundwater to cause solid particles to attract, forming larger or less-soluble particles	Eliminated; groundwater will be treated at onsite water treatment plant
		 Air Stripping	A mass transfer process in which volatile groundwater contaminants are transferred to gas phase	Eliminated; groundwater will be treated at onsite water treatment plant
		 X-ray Treatment, Solar Detonation, Gamma Irradiation, Ultraviolet Photolysis	Processes which decompose organic contaminants to non-toxic or less toxic components using radiative energy	Eliminated; groundwater will be treated at onsite water treatment plant
		 Neutralization	Addition of an acid or base to contaminated groundwater to adjust its pH to 7	Eliminated; groundwater will be treated at onsite water treatment plant
		 Precipitation (5)	Chemicals are mixed into contaminated groundwater to transform dissolved metals or radionuclides to solid phase	Eliminated; groundwater will be treated at onsite water treatment plant
	 Onsite Water Treatment Plant	 Distillation, Desorption, Ultraviolet, Ozonation	The removal of halogenated (C1, Bx, etc.) organic components from contaminated groundwater	Eliminated; groundwater will be treated at onsite water treatment plant
			Treatment of VOCs and radionuclides of existing onsite water treatment plant ( )	Potentially applicable*

LEGEND

 Technology or process option eliminated from further evaluation  
 Note: Use of ON/OUT treatment plant is potentially viable


(Continued next page)

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Figure 3 (Sheet of 9)  
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 Technical Memorandum No.  
 Initial Technology Screening  
 for Groundwater

Groundwater General Response Action	Remedial Technology	Process Options	Description	Screening Comment
Ex Situ Treatment	Chemical/Physical	<div>Reduction/Oxidation</div> <div>Ozonation, High-Energy Electron Irradiation, Wet Oxidation, Supercritical Water Oxidation, UV/H<sub>2</sub>O<sub>2</sub> Oxidation, Thermal Gas-Phase Reduction, Deep-Shell Wet Air Oxidation (6)</div>	Reduction/oxidation converts hazardous contaminants to non-hazardous or less toxic compounds that are more stable and/or inert, by the addition of reducing/oxidizing agents	Eliminated; groundwater will be treated at on-site water treatment plant
			Membranes used to separate/concentrate contaminants from contaminated groundwater	Eliminated; groundwater will be treated at on-site water treatment plant
		<div>Membrane Processes, Reverse Osmosis, Electrochemical Metal Removal, Micro-Filtration, Ultra-Filtration (7)</div>	Contaminated groundwater is passed through resin bed where ion species are transferred to resin	Eliminated; groundwater will be treated at on-site water treatment plant
			Addition of solvent to contaminated groundwater separates soluble and insoluble components	Eliminated; groundwater will be treated at on-site water treatment plant
			Suspended solids are removed by forcing contaminated groundwater through porous medium	Eliminated; groundwater will be treated at on-site water treatment plant
		Ion Exchange		
		Solvent Extraction		
		Filtration (6)		
		<div>Incineration, Oxygen-Enhanced, Fluidized Bed, Rotary Kiln, Submerged Quench, Liquid Injection, Circulating Bed, Cement Kilns</div>	Oxygen or air/oxygen mixture used to thermally combust or decompose the organic waste	Eliminated; groundwater will be treated at on-site water treatment plant
	Thermal	Cyclone Furnace	Organic contaminants react to form innocuous products; solids and metals are volatilized into gases or slag	Eliminated; groundwater will be treated at on-site water treatment plant
		Freeze Crystallization	Separation technique that removes heat from the waste to form an ice crystalline structure that naturally excludes contaminants from the ice molecule matrix	Eliminated; groundwater will be treated at on-site water treatment plant
		Evaporation, Distillation, Steam Stripping (8)	Separation of contaminants by differences in volatility. Distillation is simply the process of evaporation followed by condensation. Steam stripping is essentially continuous fractional distillation process carried out in packed or tray tower	Eliminated; groundwater will be treated at on-site water treatment plant

LEGEND

 Technology or process option eliminated from further evaluation

NOTE: Process options are components of the following treatment systems or studies:

- (1) Surfactant-Enhanced Aquifer Remediation (SEAR)
- (2) AirSparging Process
- (3) Adsorptive Filtration
- (4) ColdFiltration Filter Method
- (5) Adsorptive Filtration
- (6) Activated Carbon Adsorption
- (7) Activated Carbon Adsorption
- (8) ColdFiltration Filter Method
- (9) Activated Carbon Adsorption
- (10) Activated Carbon Adsorption
- (11) Activated Carbon Adsorption
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Operator Unit No.  
Technical Management No.  
Title: Activated Carbon Adsorption  
for Groundwater

Surface Soil General Response Action	Remedial Technology	Process Options	Effectiveness	Implementability	Cost
No Further Action	None	Not Applicable	Does not achieve CRIAOs	Difficult regulatory/community acceptance	None
Institutional Controls	Access Restrictions	Fencing, Security	May achieve CRIAOs. Effectiveness depends on continued future implementation. Does not reduce contamination	Difficult regulatory/community acceptance	Low capital, low O&M
		Deed Restrictions	May achieve CRIAOs. Effectiveness depends on continued future implementation. Does not reduce contamination	Difficult regulatory/community acceptance	Low capital, low O&M
		Land Use Restrictions	May achieve CRIAOs. Effectiveness depends on continued future implementation. Does not reduce contamination	Difficult regulatory/community acceptance	Low capital, low O&M
		Monitoring	Effective monitoring method	Easily implemented	Low capital, low O&M
Containment	Horizontal Barriers	Vegetative Cover	May achieve CRIAOs with restrictions on future land use	Easily implemented.	Low capital, low O&M
		Asphalt-Based Cover	May achieve CRIAOs with restrictions on future land use	Easily implemented.	Low capital, low O&M
		Compacted-Clay Cover	May achieve CRIAOs with restrictions on future land use	Easily implemented	Med capital, low O&M
		Multi-Layer Cover	May achieve CRIAOs with restrictions on future land use	Easily implemented.	High capital, med O&M
In situ Treatment	Solidification/Stabilization	Stabilization, Slurry Injection, Solidification, Cementation, Encapsulation	Effectiveness and reliability evaluations require treatability study. Long-term effectiveness suspect.	Average implementability	Insufficient data

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Figure 4 (Sheet 4 of 5)  
Operable Unit No. 2  
Technical Memorandum No.  
Technology Evaluation for  
Surface Soils

#### LEGEND

Technology or process option eliminated from further evaluation  
Notes. Cost evaluation is relative only within remedial technology groupings.

(Continued next page)

Surface Soil General Response Action	Remedial Technology	Process Options	Effectiveness	Implementability	Cost
Removal	Excavation	Soil Excavation	Appears to meet C/R/Os. Would require controls to prevent mobilization of contaminants	Easily implemented	Low capital, low O&M
	Short Distance Transport	Conveyor System	Effective; contaminants are removed. Would require controls to prevent mobilization of contaminants	Easily implemented	High capital, med O&M
		Slurry Pipeline	Effective; contaminants are removed. Would require controls to prevent mobilization of contaminants	Easily implemented	High capital, high O&M
	Long Distance Transport	Truck/Pneum. Hauling	Effective; contaminants are removed. Would require controls to prevent mobilization of contaminants	Easily implemented DOT permit may be required	High capital, low O&M
	Offsite Storage/Disposal	Landfill/TSD Facility	Effective; reduces mobility of contaminants. Would require controls to prevent mobilization of contaminants	Easily implemented	High capital, low O&M
	Onsite Storage/Disposal	Disposal Vault	Effective; reduces mobility of contaminants. Would require controls to prevent mobilization of contaminants	Difficult implementation; would require permits, and construction of onsite TSD facility	High capital, low O&M
		Container Storage	Effective; reduces mobility of contaminants. Would require controls to prevent mobilization of contaminants	Difficult implementation; RFETS has permitted storage areas; however capacity may be limited. Long-term storage may not be acceptable	Low capital, med O&M
		Permitted Landfill	Effective; reduces mobility of contaminants. Would require controls to prevent mobilization of contaminants	Difficult implementation; would require permits and construction of onsite TSD facility	High capital, med O&M

LEGEND

☒ Technology or process option eliminated from further evaluation

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Figure (Sheet of 2)

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Technology Evaluation for  
Surface Soils

(Continued next page)

Surface Soil General Response Action	Remedial Technology	Process Options	Effectiveness	Implementability	Cost
Ex situ Treatment	Chemical/Physical	Chemical Red/Ox (1)	Effectiveness and reliability evaluations require treatability study. Current work at INEL on U looks promising.	Insufficient data available to rate this process option.	Insufficient data
		Soil Washing (2)	Effectiveness and reliability evaluations require treatability study. Current treatability work looks promising.	Average Implementability	Med capital, med O&M
		Electrokinetics	Effectiveness and reliability evaluations require treatability study. Current work on Cr, Hg, and U looks promising.	Difficult implementation, innovative technology	High capital, med O&M
		Physical Separation (4)	Effectiveness and reliability evaluations require treatability study. Current work on Ra, and U looks promising.	Easily implemented	Low capital, low O&M
		Magnetic Separation (5)	Effectiveness and reliability evaluations require treatability study. Current work at RFETS and INEL looks promising.	Difficult implementation, innovative technology	Insufficient data
	Biological	Biological Leaching (6)	Effectiveness and reliability evaluations require treatability study. Work at RFETS in early stages.	Insufficient data available to rate this process option.	Insufficient data
		Stabilization (7)	Effectiveness and reliability evaluations require treatability study. Effectiveness for heavy metals is established.	Average Implementability TSD service for heavy metals may be applicable	Insufficient data
	Solidification/Stabilization	Encapsulation	Effective, appears to meet CRAOs. Would require controls to prevent mobilization of contaminants.	Average Implementability	Medium capital, med O&M
		Cementation	Average effectiveness appears to meet CRAOs. Would require controls to prevent mobilization of contaminants.	Easily implemented	Low capital, med O&M
		Vitrification (Plasma Arc, Slagging Furnace, Joule-Heated, Glass Melter)	Effective, appears to meet CRAOs. Would require controls to prevent mobilization of contaminants.	Average Implementability	Medium-high capital, med-high O&M

NOTE: Process options are components of the following treatment systems or studies:

- (1) Aqueous Biphasic Separation (ABS)

(2) TRU Clean®

Gravimetric/Chemical Enhancement (NRT Study)

Chemically Enhanced Steam Stripping (CESS)

Chelating Agents (LANL Study)

(3) CEPOD Process (PHL)

B.E.S.T. Process
- (4) Aqueous Biphasic Separation (ABS)

Air Stripped Hydrocarbons (ASH)

TRU Clean®

Gravimetric/Chemical Enhancement (NRT Study)

(5) High Gradient Magnetic Separation (HGMS)

(6) MBX Study (Lockheed)

(7) WES-PHX Process

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Figure (Sheet of 3)  
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Surface Soils

S Surface Soil General Response Action	Remedial Technology	Process Options	Effectiveness	Implementability	Cost
No Further Action	None	Not Applicable	Does not achieve CRAOs in source areas	Difficult regulatory/community acceptance	None
Institutional Controls	Access Restrictions	Fencing, Security, etc.	Does not achieve CRAOs in source areas	Difficult regulatory/community acceptance	Med capital, low O&M
	Land Use Restrictions	Deed Restrictions	Effectiveness depends on continued future implementation. Does not reduce contamination	Difficult regulatory/community acceptance	Low capital, no O&M
	Monitoring	Zoning Restriction	Effectiveness depends on continued future implementation. Does not reduce contamination	Difficult regulatory/community acceptance	Low capital, no O&M
		Groundwater Monitoring	Effective monitoring method	Easily implemented	Low capital, low O&M
Containment	Vertical Barriers	Vadose Zone Monitoring	Effective monitoring method	Easily implemented	Low capital, low O&M
		Slurry Wall	Effective. Reduces contaminant vehicle migration	Easily implemented	Med capital, low O&M
	Horizontal Barriers	Synthetic Membrane Curtail Wall	Effective. Reduces contaminant vehicle migration	Easily implemented	Med-High capital, low O&M
		Asphalt-Based Cover	Effective. Reduces contaminant vehicle migration	Implementable	Med capital, med O&M
		Compacted-Clay Cover	Effective. Reduces contaminant vehicle migration	Implementable	Low capital, high O&M
		Multi-Layer Cover	Effective. Reduces percolation infiltration and contaminant mobility	Difficult Implementation	High capital, med O&M
		Vegetated Cover	Effective. Reduces percolation infiltration and contaminant mobility	Easily implemented	Low capital, low O&M
	Biological	Enhanced Bioremediation	Effective for some organic COCs in source areas but not all	Implementable	Med capital, low O&M
		Pneumatic Fracturing	Not applicable to meet CRAOs. This option is used to enhance other <i>in situ</i> processes	Easily implemented	Low capital, low O&M
		Soil Gas Venting	Not completely effective for source area. May be effective for residual soil contamination	Easily implemented	Low capital, low O&M
		Soil Vapor Extraction	Moderately effective for VOCs	Easily implemented	Med capital, med O&M
In situ Treatment	Chemical/Physical	Electrokinetics	Effectiveness and reliability evaluations require treatability study. Current work on Cr, Hg and U looks promising. Does not address COCs.	Difficult Implementation. Has not been proven	Med capital, med O&M
		Electrochemical Soil Decontamination	Not effective	Implementable	Med capital, med O&M

LEGEND

Technology or process option eliminated from further evaluation

Subsurface Soil General Response Action	Remedial Technology	Process Options	Effectiveness	Implementability	Cost	
Removal	Solidification/Stabilization	Stabilization	Effective, reduces contaminant mobility	Implementable	Med capital, med O&M	
		Cementation	Effective, reduces contaminant mobility	Implementable	Med capital, low O&M	
		Vitrification	Effective, reduces contaminant mobility off-gas treatment required	Difficult implementation	High capital, high med O&M but no long-term O&M	
	Thermal	Thermally Enhanced Soil Vapor Extraction	Effective for VOCs off-gas treatment required	Implementable	Med capital, med O&M	
	Excavation	Soil Excavation	Effective, contaminants are removed	Implementable	High capital, low O&M	
		Short Distance Transport	Conveyor System	Effective, contaminants are removed. Would require controls to prevent mobilization of contaminants	Implementable	High capital, med O&M
			Truck Hauling	Effective, contaminants are removed. Would require controls to prevent mobilization of contaminants	Implementable	Low capital, low O&M
			Truck/Rail Hauling	Effective, contaminants are removed. Would require controls to prevent mobilization of contaminants	Implementable DOT permits may be required	Low capital, low O&M
		Onsite Storage/Disposal	Landfill/TSD Facility	Effective, reduces contaminant mobility	Easily Implemented	High capital, low O&M
			Disposal Vault	Effective, reduces contaminant mobility	Difficult implementation, would require permits and construction of onsite TSD facility	High capital, low O&M
		Onsite Storage/Disposal	Container Storage	Effective, reduces contaminant mobility	Difficult implementation, RFETS has permitted storage areas; however capacity may be limited. Long-term storage may not be acceptable	Low capital, med O&M
			Permitted Landfill	Effective, reduces contaminant mobility	Difficult implementation, would require permits, and construction of onsite TSD facility	High capital, med O&M

LEGEND

☒

 Technology or process option eliminated from further evaluation

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Figure 5 (Sheet 2 of 4)

Operable Unit No. 2

Technical Memorandum No. 2

Technology Evaluation for

Subsurface Soils

(continued next page)

Subsurface Soil General Response Action	Remedial Technology	Process Options	Effectiveness	Implementability	Cost
Ex situ Treatment	Chemical/Physical	Chemical Redox (1)	Effectiveness and reliability evaluations require treatability study Current work at INEL looks promising	Insufficient data	Insufficient data
		Soil Washing (2)	Effective, appears to meet CRAOs. Would require controls to prevent mobilization of contaminants	Easily implemented after excavation	High capital, med O&M
		Solvent Extraction (3)	Effectiveness and reliability evaluations require treatability study Current work on Ra, Th, and U looks promising	Implementability TSD service for U may be applicable	High capital, med O&M
		Derivatization	Effective for VOCs	Difficult implementation in soils	Med capital, high O&M
		Soil Vapor Extraction	Effective for VOCs, off-gas treatment required	Easily implemented	Low capital, low O&M
		Electrokinetics	Not effective for COCs	Implementable	Med capital, med O&M
		Physical Separation (4)	Effectiveness and reliability evaluations require treatability study Current work on Ra, and U looks promising	Implementable	Low capital, low O&M
		Magnetic Separation (5)	Appears effective and capable of meeting CRAOs. Current work at INEL and RFP looks promising	Difficult implementation innovative technology	Insufficient data
	Solidification/Stabilization	Stabilization (6)	Effectiveness and reliability evaluations require treatability study Current work on heavy metals looks promising	Implementable after excavation	Insufficient data
		Encapsulation	Effective, appears to meet CRAOs. Would require controls to prevent mobilization of contaminants	Easily implemented after excavation	Med capital, med O&M
		Cementation	Effective, appears to meet CRAOs. Would require controls to prevent mobilization of contaminants	Easily implemented after excavation	Low capital, med O&M
		Verification: (Plasma Arc, Slagging, Furnace Joule-Heated, Glass Melter)	Effective appears to meet CRAOs. Would require controls to prevent mobilization of contaminants	Easily implemented after excavation	High capital, high O&M

(continued next page)

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Technical Memorandum No.  
Technology Evaluation for  
Subsurface Soils

Subsurface Soil General Response Action	Remedial Technology	Process Options	Effectiveness	Implementability	Cost
Ex situ Treatment	Thermal	Inertion: Fluidized Bed, Infrared, Molten Salt, Solar Multiple Heaters, Microwave Melting, Molten Metal Reactor Rotary Kilo, Oxygen-Enhanced, Liquid Injection, High Temperature Fluid Wall	Effective for VOCs. Would require controls to prevent mobilization of contaminants	Implementable	High capital, high O&M
		Low-Temperature Thermal Desorption	Effective for VOCs. Would require controls to prevent mobilization of contaminants.	Implementable	Med capital, med O&M
		HTS Thermal Distillation Process	Effective for VOCs. Would require controls to prevent mobilization of contaminants.	Implementable	Med capital, med O&M
		Pyrolysis	Effective for VOCs. Would require controls to prevent mobilization of contaminants.	Implementable	Med capital, med O&M

NOTE: Process options are components of the following treatment systems or studies:

(1) Aqueous Biphasic Separation (ABS)  
(2) TRU Clean®  
Surfactant Enhanced Remediation  
Gravity/Floation/Chemical Enhancement (NRT Study)  
Aqueous Biphasic Separation  
Chemically Enhanced Steam Stripping (CESS)  
Chelating Aqueous (LANL Study)  
(3) CEPOD Process (PNL)  
BEST Process

(4) Aqueous Biphasic Separation (ABS)  
Surfactant Enhanced Remediation  
Air Sparged Hydrocyclones (ASH)  
TRU Clean®  
Gravity/Floation/Chemical Enhancement (NRT Study)  
(5) High Gradient Magnetic Separation (HGMS)  
(6) WES-PHX Process

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Technology Evaluation for  
Subsurface Soils

Groundwater General Response Action	Remedial Technology	Process Options	Effectiveness	Implementability	Cost
No Further Action	Intrinsic Remediation	Groundwater Monitoring	Effective for VOCs, reduces toxicity	Easily implemented	Low capital, no O&M
Institutional Controls	Access Restrictions	Fencing, Security	Effective for VOCs and radionuclides; reduces exposure	Easily implemented	Low capital, low O&M
		Lock Out/Tag Out Wells	Effective for VOCs and radionuclides; reduces exposure	Easily implemented	Low capital, negligible O&M
		Deed Restrictions	Effective for VOCs and radionuclides; reduces exposure	Easily implemented	Low capital, no O&M
		Zoning Restrictions	Effective for VOCs and radionuclides; reduces exposure	Easily implemented	Low capital, no O&M
		Regulatory Restrictions	Effective for VOCs and radionuclides; reduces exposure	Easily implemented	Low capital, no O&M
Containment	Intrinsic Remediation	Groundwater Monitoring	Effective for VOCs; reduces toxicity	Easily implemented	Low capital, no O&M
		Enhanced Soil Cap, Revegetation, Grading, and Compaction	Effective for VOCs and radionuclides; reduces mobility	Easily implemented	Low capital, low O&M
		Interceptor Trenches and Local Extraction Wells	Effective for VOCs and radionuclides; reduces mobility	Easily implemented	Low capital, low O&M
		Sheet Piling	Effective for VOCs and radionuclides; reduces mobility	Difficult to implement	Moderate capital, low O&M
		Slurry Wall	Effective for VOCs and radionuclides; reduces mobility	Easily implemented	Moderate capital, low O&M
	Vertical Barriers	Synthetic Membrane Cutoff Wall	Effective for VOCs and radionuclides; reduces mobility	Easily implemented	Low capital, low O&M
		Asphalt-Type Cover	Effective for VOCs and radionuclides; reduces mobility	Easily implemented	Low capital, low O&M
		Compacted Clay Cover	Effective for VOCs and radionuclides; reduces mobility	Easily implemented	Low capital, low O&M
	Horizontal Barriers	Alkali-Layer Cover	Effective for VOCs and radionuclides; reduces mobility	Easily implemented	High capital, moderate O&M

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Technology Evaluation  
for Groundwater

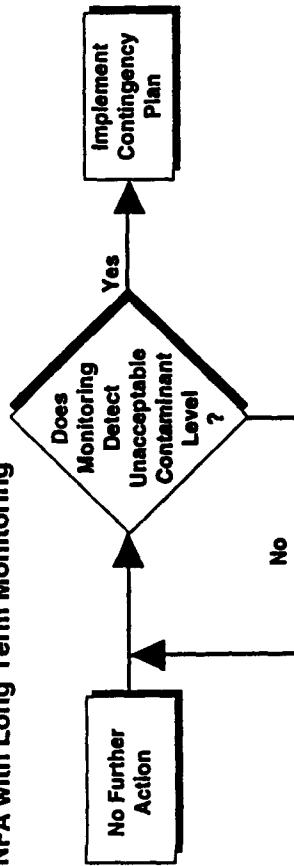
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Groundwater General Response Action	Remedial Technology	Process Options	Effectiveness	Implementability	Cost
Removal	Groundwater Extraction	Interceptor Trenches and Local Extraction Wells	Effective for VOCs and radionuclides; reduces mobility and volume	Easily implemented	Low capital; low O&M
	Groundwater Transport	Truck/Rail Hauling Pipeline			
	Disposal	RFETS STP			
In Situ Treatment	Enhanced Bioremediation	Enhancement of aerobic or anaerobic conditions, comestibic substrates	Effective for VOCs; reduces toxicity	Insufficient data	Low capital; low O&M
	Chemical/Physical	Air Sparging	Effective for VOCs; reduces toxicity	Easily implemented	Low capital; low O&M
	Thermal	Passive Treatment Wall	Effective for VOCs and radionuclides; reduces toxicity	Insufficient data, pilot scale technology	Moderate capital; low O&M
		T-SVE			
Ex Situ Treatment	Chemical/Physical	Onsite Water Treatment Plant	Effective for VOCs and radionuclides; reduces toxicity	Easily implemented	Low capital; low O&M

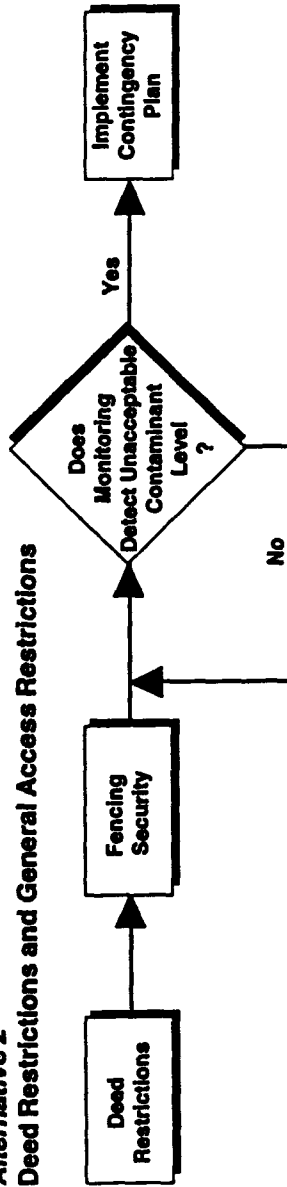
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Technology Evaluation  
for Groundwater

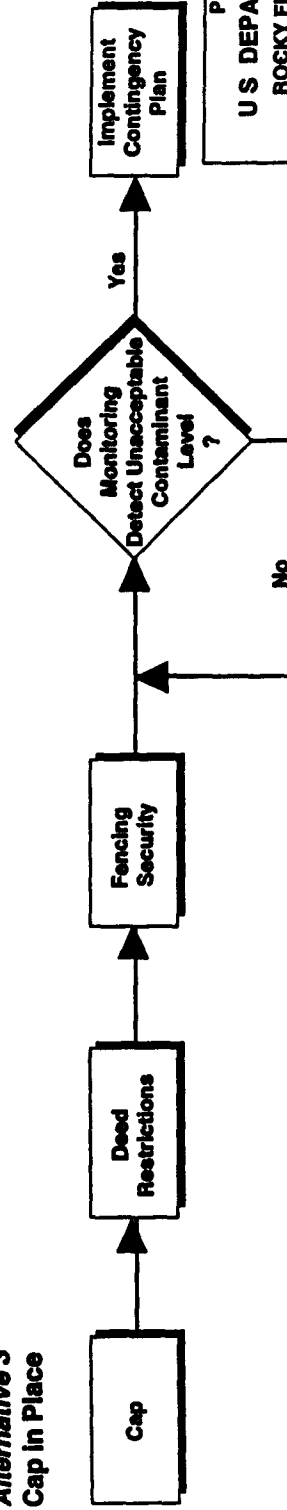
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Alternative 1  
NFA with Long Term Monitoring**



**Surface Soil Source/Institutional Controls  
Alternative 2  
Deed Restrictions and General Access Restrictions**



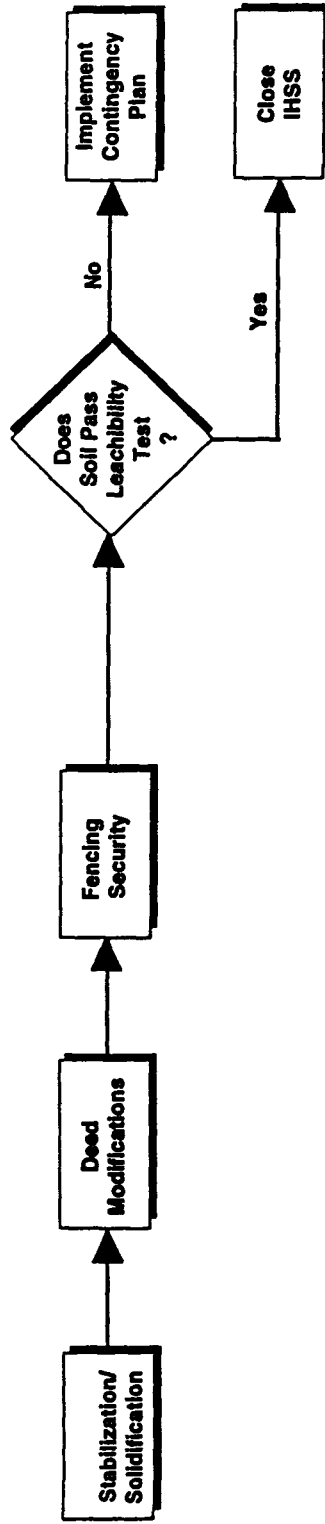
**Surface Soil Source/Containment  
Alternative 3  
Cap in Place**



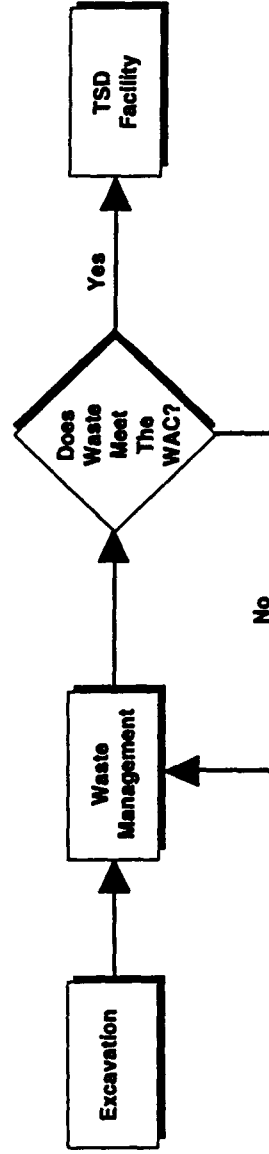
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Figure 5.1  
Operable Unit No. 2  
Technical Memorandum No. 2  
OU2 Surface Soil Source Area  
(Radionuclides)

**Surface Soil Source/In Situ Treatment  
Alternative 4  
In Situ Stabilization**



**Surface Soil Source/Removal  
Alternative 5  
Excavation and Disposal**

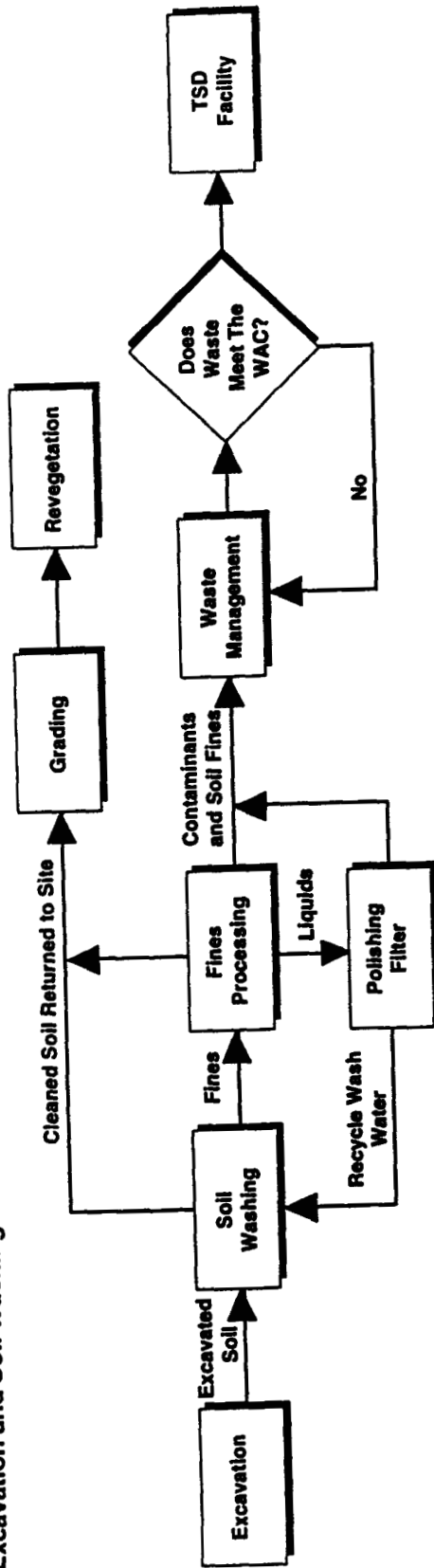


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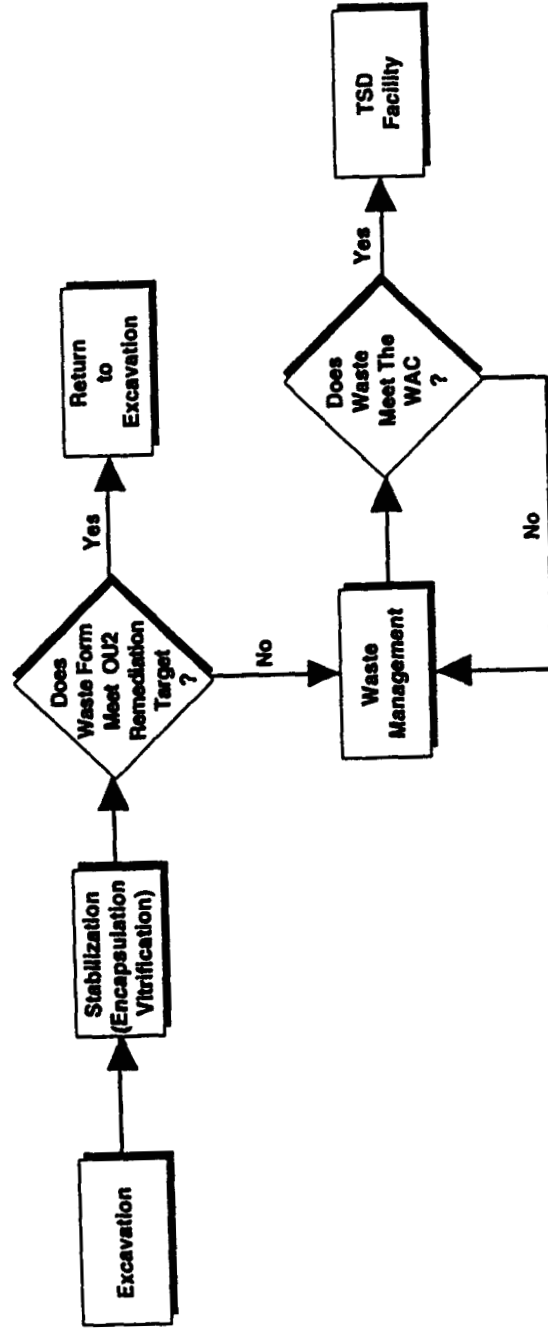
Figure 5 2

Operable Unit No 2  
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OU2 Surface Soil Source Area  
(Radionuclides)

Surface Soil Source/Ex Situ Treatment  
Alternative 6  
Excavation and Soil Washing



Surface Soil Source/Ex Situ Treatment  
Alternative 7  
Excavation Ex Situ Stabilization and Return to Excavation

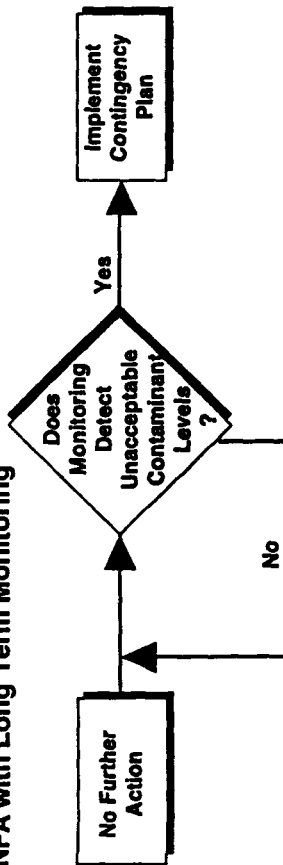


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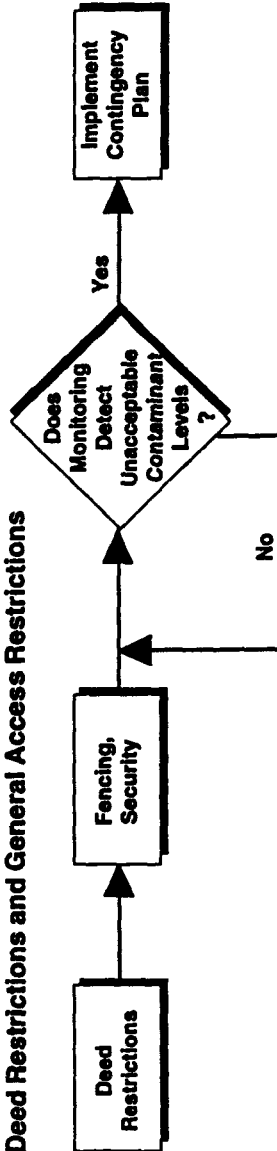
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Operable Unit No 2  
Technical Memorandum No. 2  
OU2 Surface Soil Source Area  
(Radionuclides)

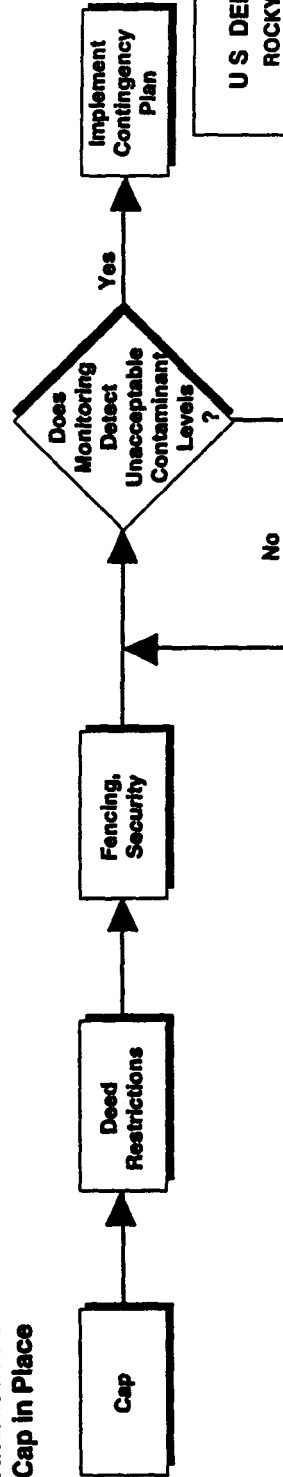
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Alternative 1  
NFA with Long Term Monitoring**



**Subsurface Soil Source/Institutional Controls  
Alternative 2  
Deed Restrictions and General Access Restrictions**



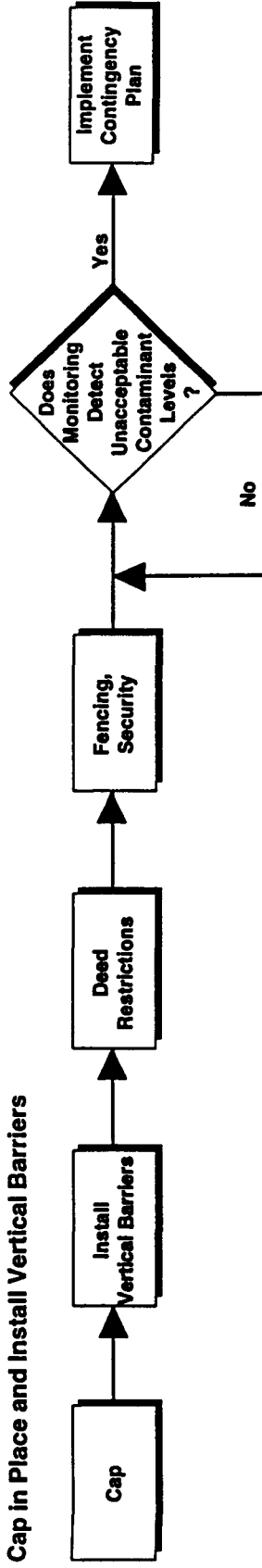
**Subsurface Soil Source/Containment  
Alternative 3  
Cap in Place**



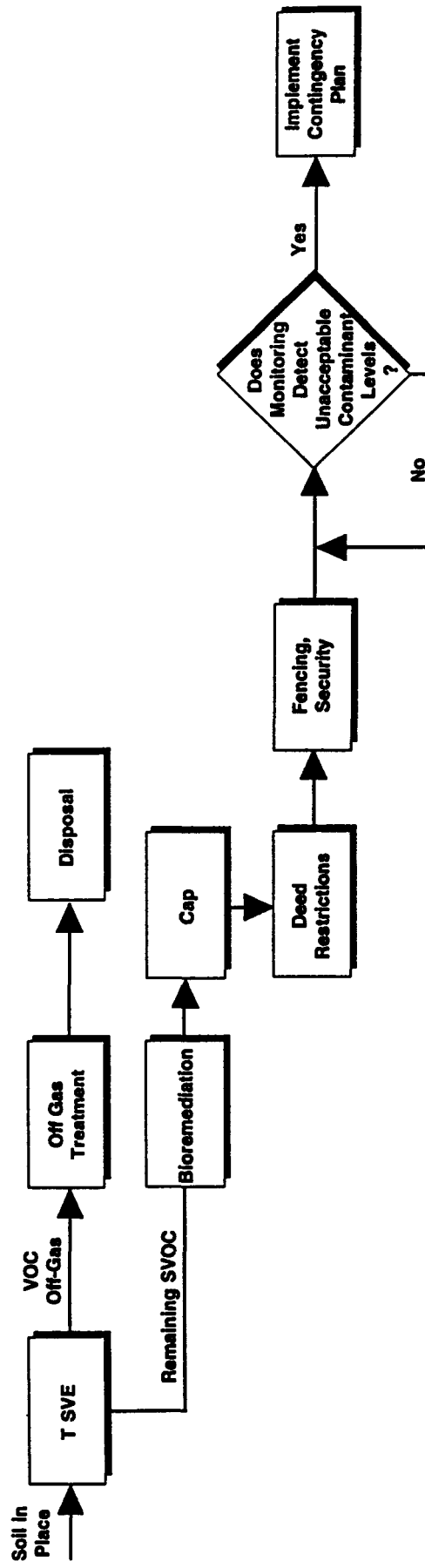
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Figure 5 4  
Operable Unit No 2  
Technical Memorandum No 2  
OU2 Subsurface Soil Source Area  
(Radionuclides, Heavy Metals and Organics)

**Subsurface Soil Source/Containment  
Alternative 4  
Cap in Place and Install Vertical Barriers**



**Subsurface Soil Source/In Situ Treatment  
Alternative 5  
Thermally Enhanced Soil Vapor Extraction Enhanced Bioremediation and Cap**

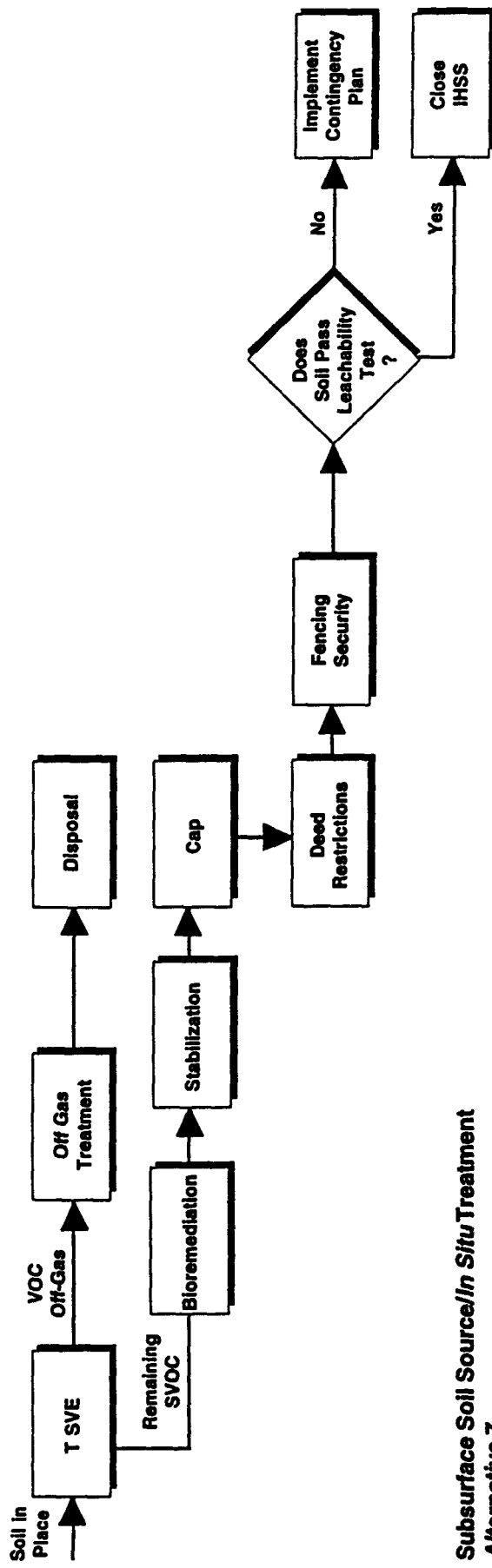


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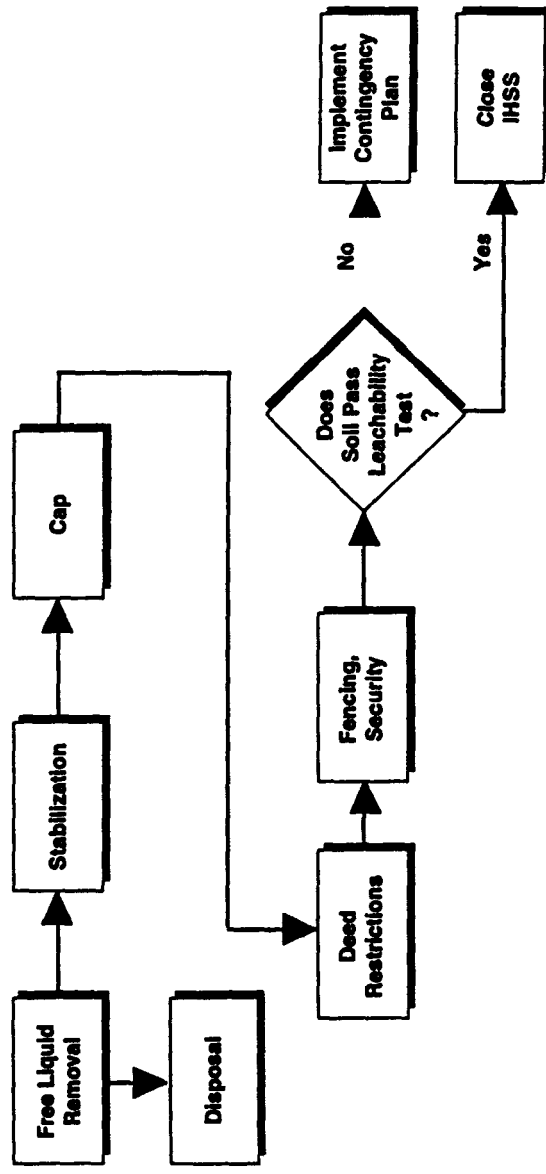
Figure 5 5

Operable Unit No. 2  
Technical Memorandum No. 2  
OU2 Subsurface Soil Source Area  
(Radionuclides Heavy Metals and Organics)

**Subsurface Soil Source/*In Situ* Treatment  
Alternative 6  
Thermally Enhanced Soil Vapor Extraction Enhanced Bioremediation Stabilization and Cap**



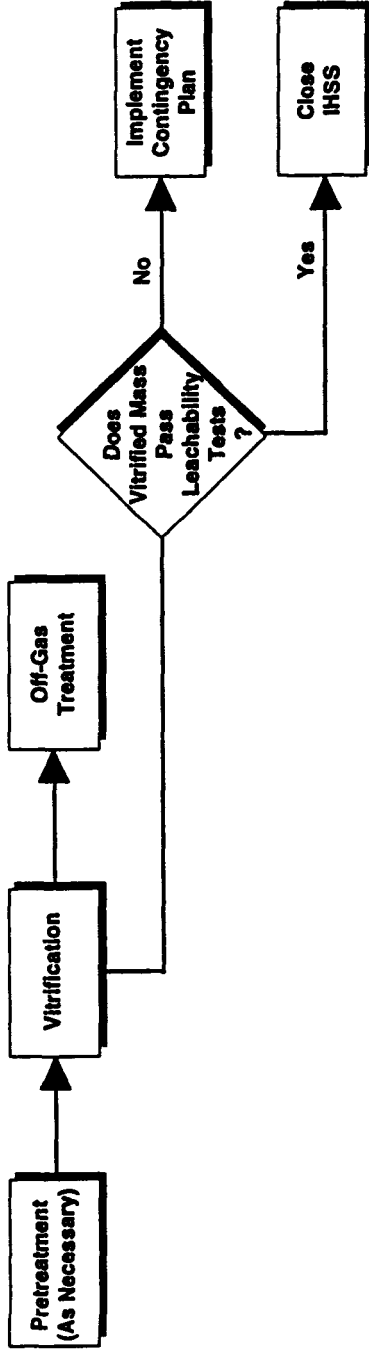
**Subsurface Soil Source/*In Situ* Treatment  
Alternative 7  
Free Liquid Removal Stabilization, and Cap**



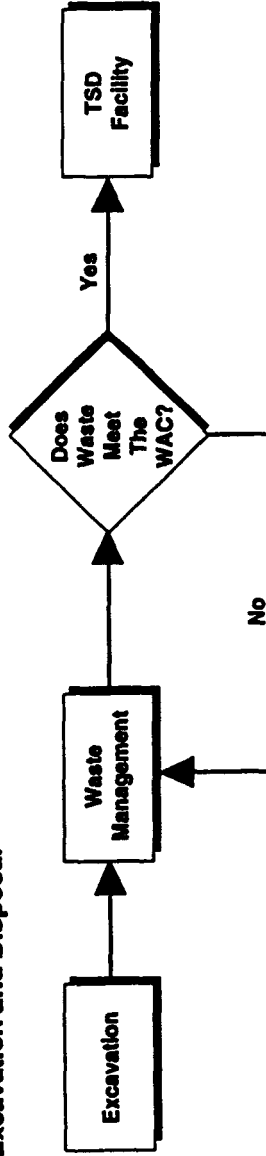
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GOLDEN COLORADO

Figure 5.6  
Operable Unit No 2  
Technical Memorandum No 2  
OU2 Subsurface Soil Source Area  
(Radionuclides, Heavy Metals and Organics)

**Subsurface Soil Source/In Situ Treatment  
Alternative 8  
In Situ Vittrification (With Pretreatment as Necessary)**



**Subsurface Soil Source/Removal  
Alternative 9  
Excavation and Disposal**

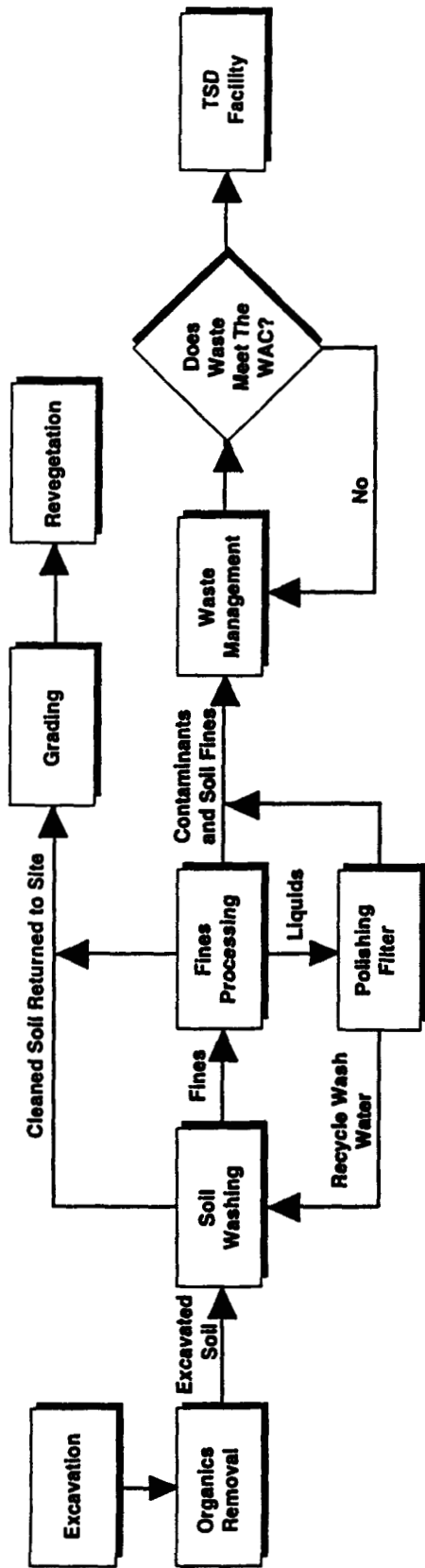


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Figure 5.7  
Operable Unit No. 2  
Technical Memorandum No. 2  
OU2 Subsurface Soil Source Area  
(Radionuclides, Heavy Metals and Organics)

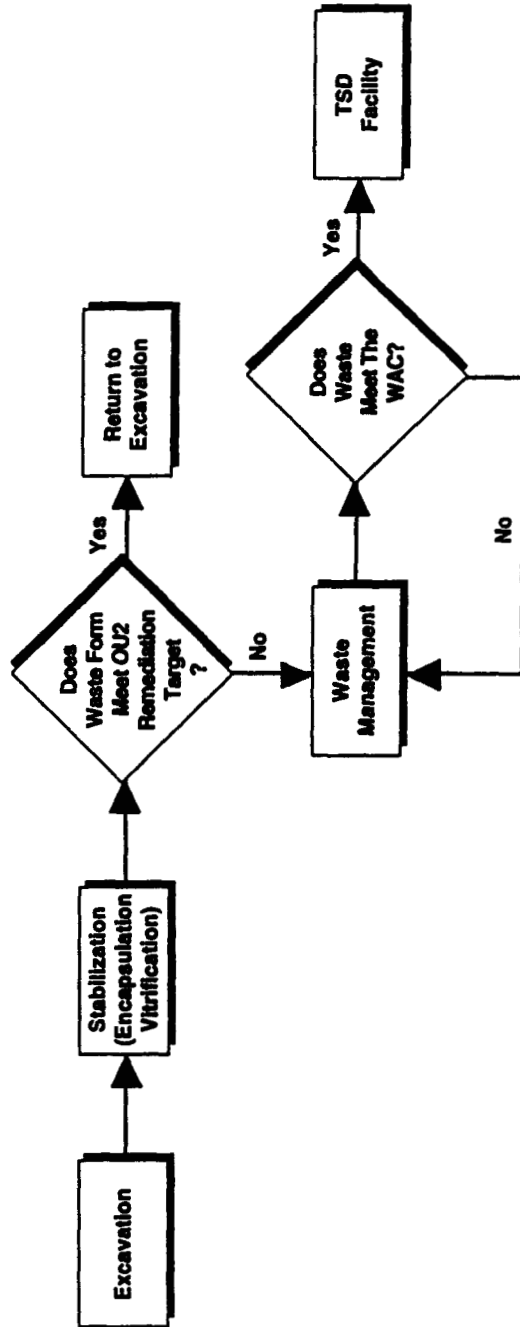
**Subsurface Soil Source/Ex Situ Treatment  
Alternative 10**

**Excavation Organics Removal and Soil Washing**



**Subsurface Soil Source/Ex Situ Treatment  
Alternative 11**

**Excavation Ex Situ Stabilization and Return to Excavation**

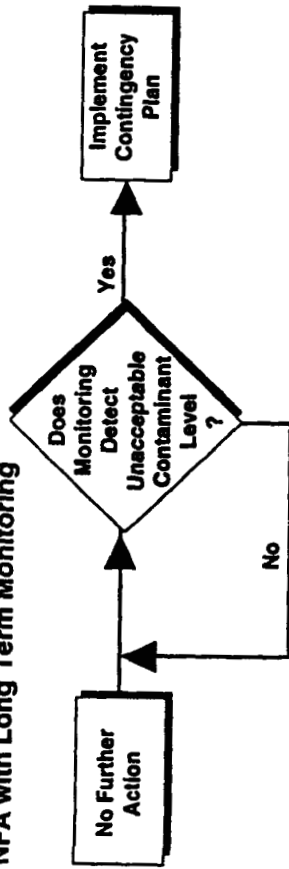


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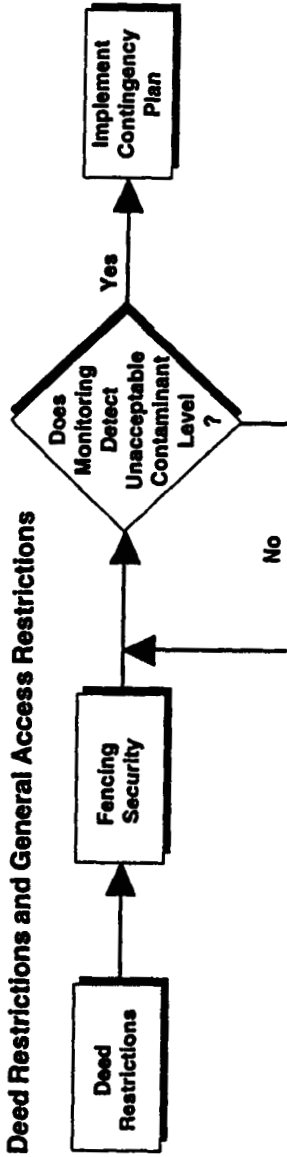
Figure 5 8

Operable Unit No 2  
Technical Memorandum No 2  
OU2 Subsurface Soil Source Area  
(Radionuclides Heavy Metals and Organics)

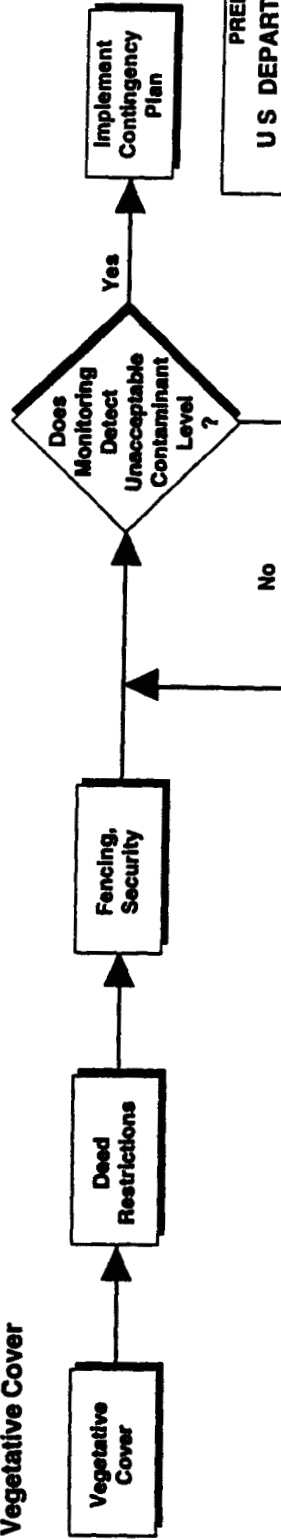
**Surface Soil Residual/No Further Action  
Alternative 1  
NFA with Long Term Monitoring**



**Surface Soil Residual/Institutional Controls  
Alternative 2  
Deed Restrictions and General Access Restrictions**



**Surface Soil Residual/Containment  
Alternative 3  
Vegetative Cover**

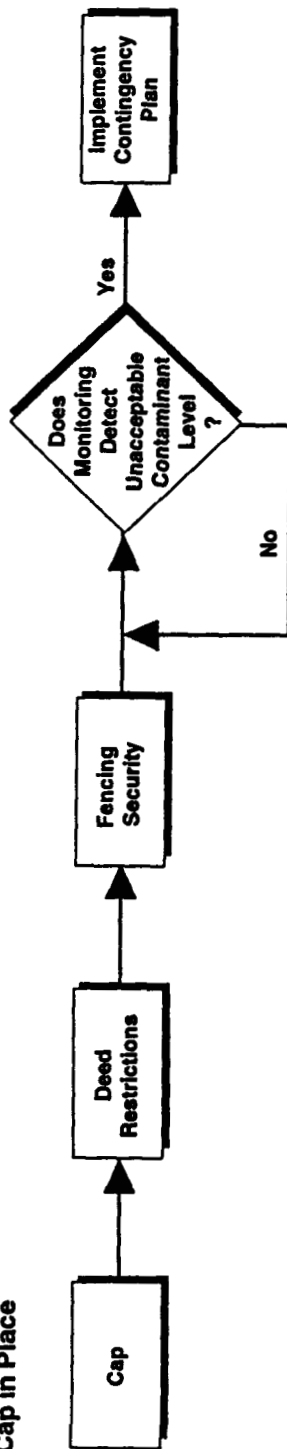


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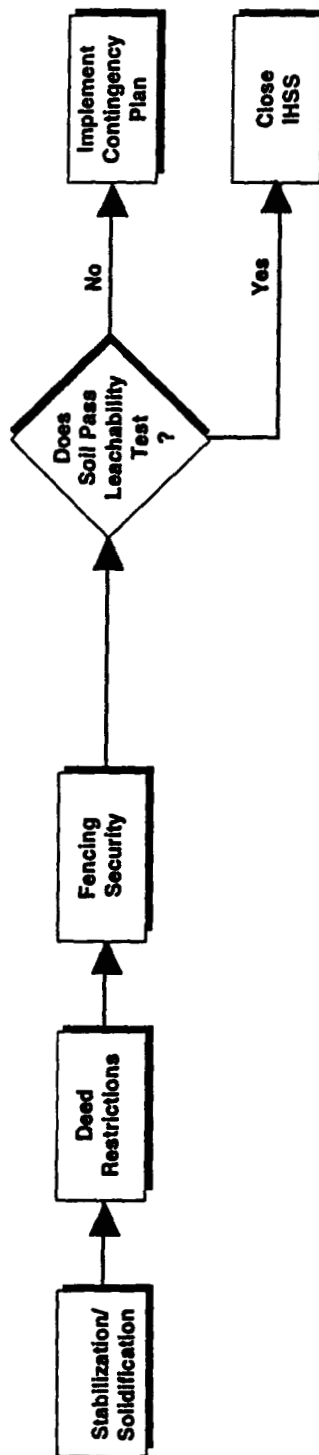
Figure 5 9

Operable Unit No 2  
Technical Memorandum No 2  
OU2 Surface Soil Residual Contamination Area  
(Radionuclides)

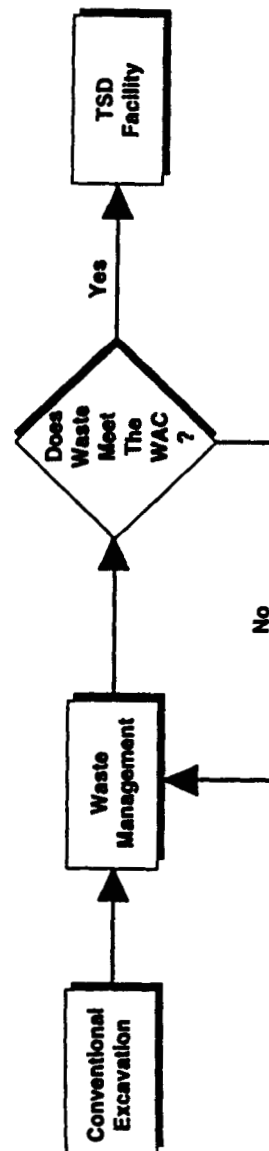
**Surface Soil Residual/Containment  
Alternative 4  
Cap in Place**



**Surface Soil Residual/In-Situ Treatment  
Alternative 5  
In Situ Stabilization/Solidification**



**Surface Soil Residual/Removal  
Alternative 6  
Excavation and Disposal**

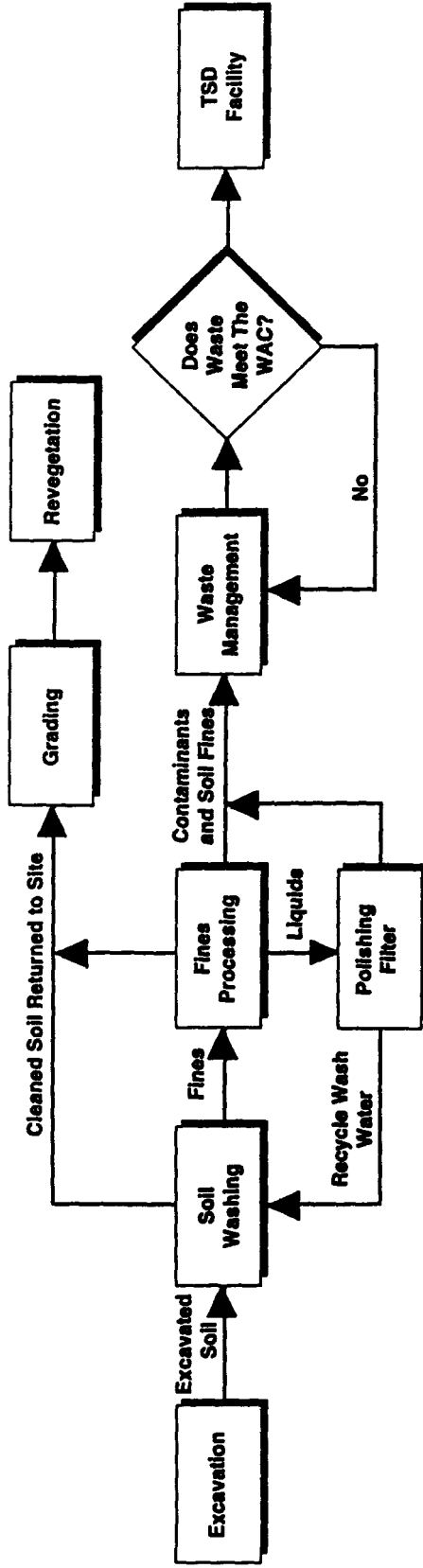


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Figure 5.10

Operable Unit No. 2  
Technical Memorandum No. 2  
OU2 Surface Soil Residual Contamination Area  
(Radionuclides)

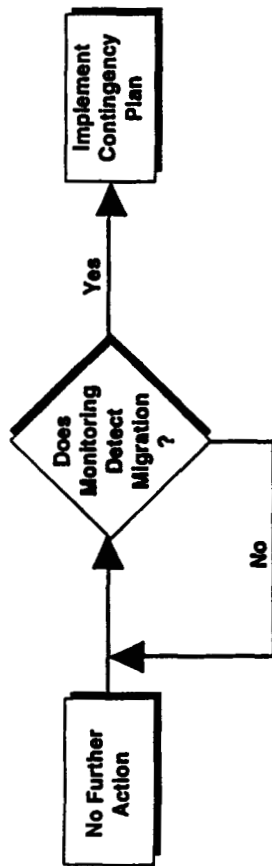
**Surface Soil Residual/Ex Situ Treatment  
Alternative 7  
Excavation and Soil Washing**



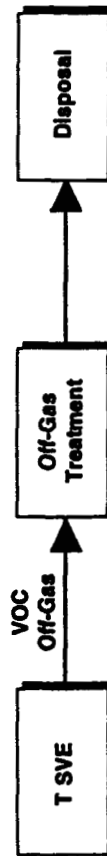
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Figure 5 11  
Operable Unit No. 2  
Technical Memorandum No. 2  
OU2 Surface Soil Residual Contamination Area  
(Radionuclides)

**Subsurface Soil Residual/No Further Action  
Alternative 1  
NFA with Long Term Monitoring**



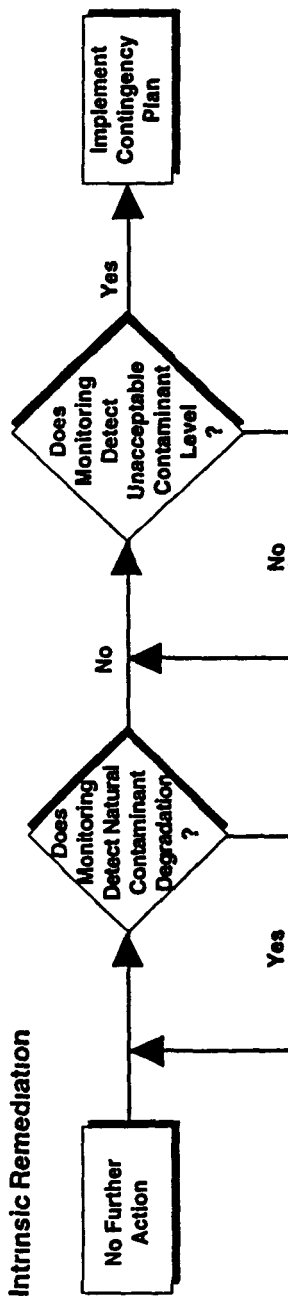
**Subsurface Soil Residual/In Situ Treatment  
Alternative 2  
Soil Vapor Extraction (Ambient or Thermally Enhanced)** (Presumptive Remedy)



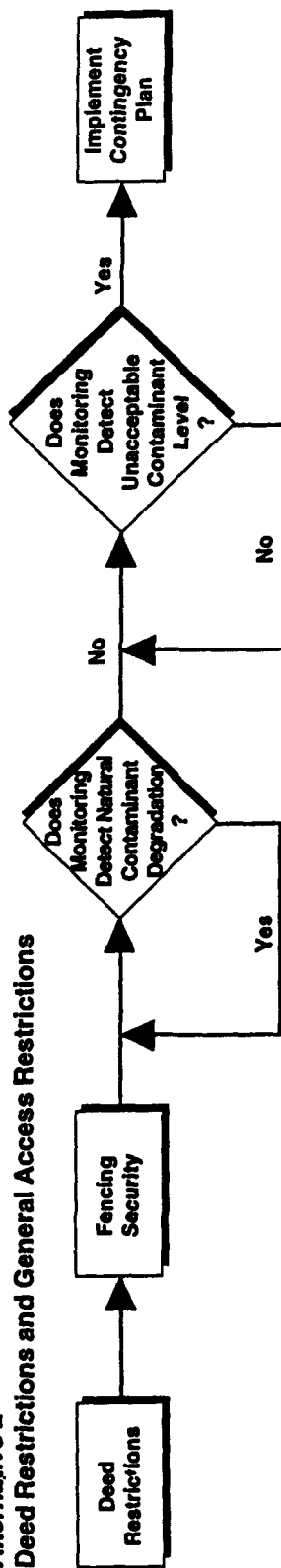
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Figure 5 12  
Operable Unit No 2  
Technical Memorandum No 2  
OU2 Subsurface Soil Residual Contamination Area  
(Radionuclides and VOCs)

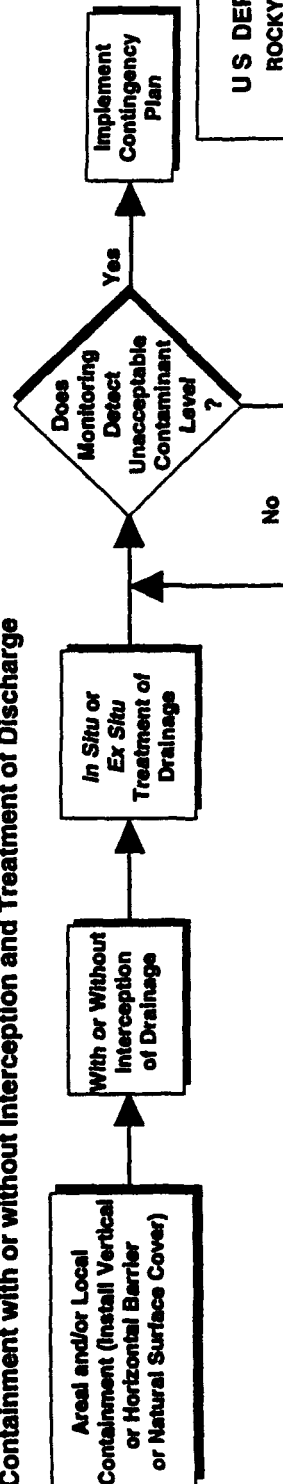
**Groundwater Contamination/No Further Action**  
**Alternative 1**  
**Intrinsic Remediation**



**Groundwater Contamination/Institutional Controls**  
**Alternative 2**  
**Deed Restrictions and General Access Restrictions**



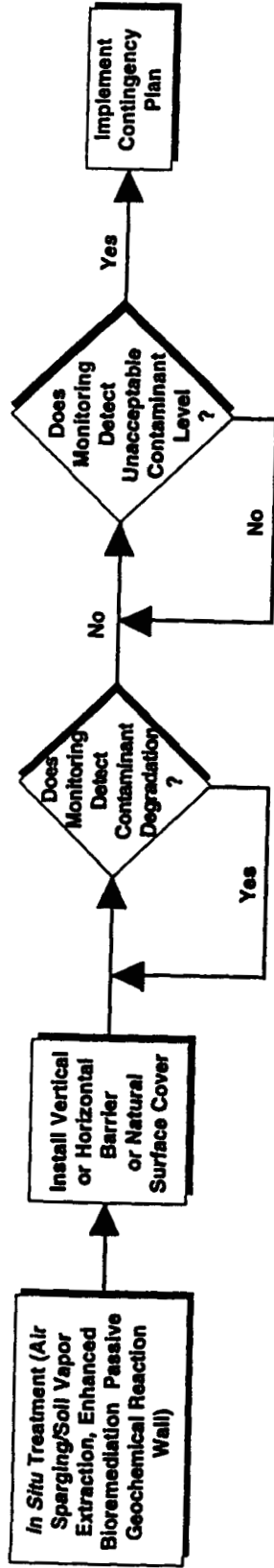
**Groundwater Contamination/Containment**  
**Alternative 3**  
**Containment with or without Interception and Treatment of Discharge**



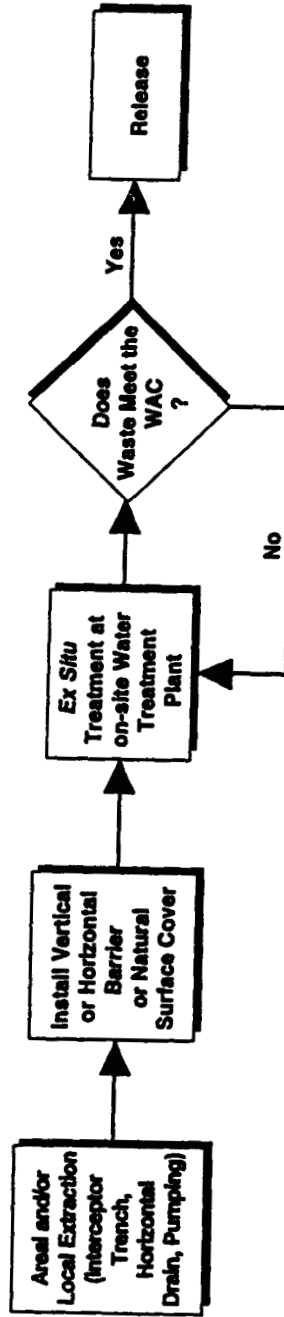
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Figure 5-13  
 Operable Unit No. 2  
 Technical Memorandum No. 2  
 OU2 Groundwater Contamination Area  
 (Radionuclides and VOCs)

**Groundwater Contamination/*In Situ* Treatment  
Alternative 4  
*In Situ* Treatment with or without Containment**



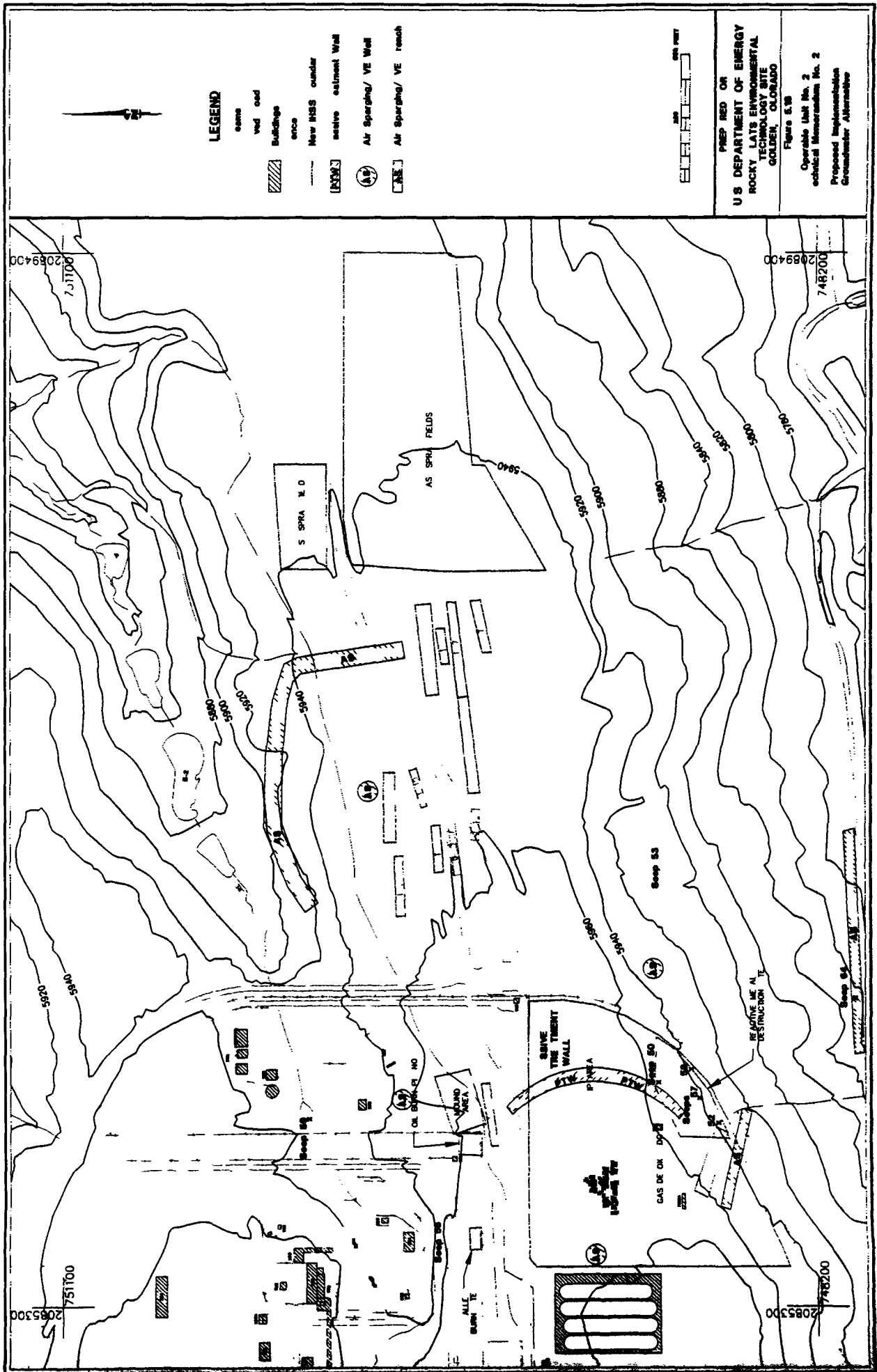
**Groundwater Contamination/*Ex Situ* Treatment  
Alternative 5  
Extraction with or without Containment, *Ex Situ* Treatment and Release**

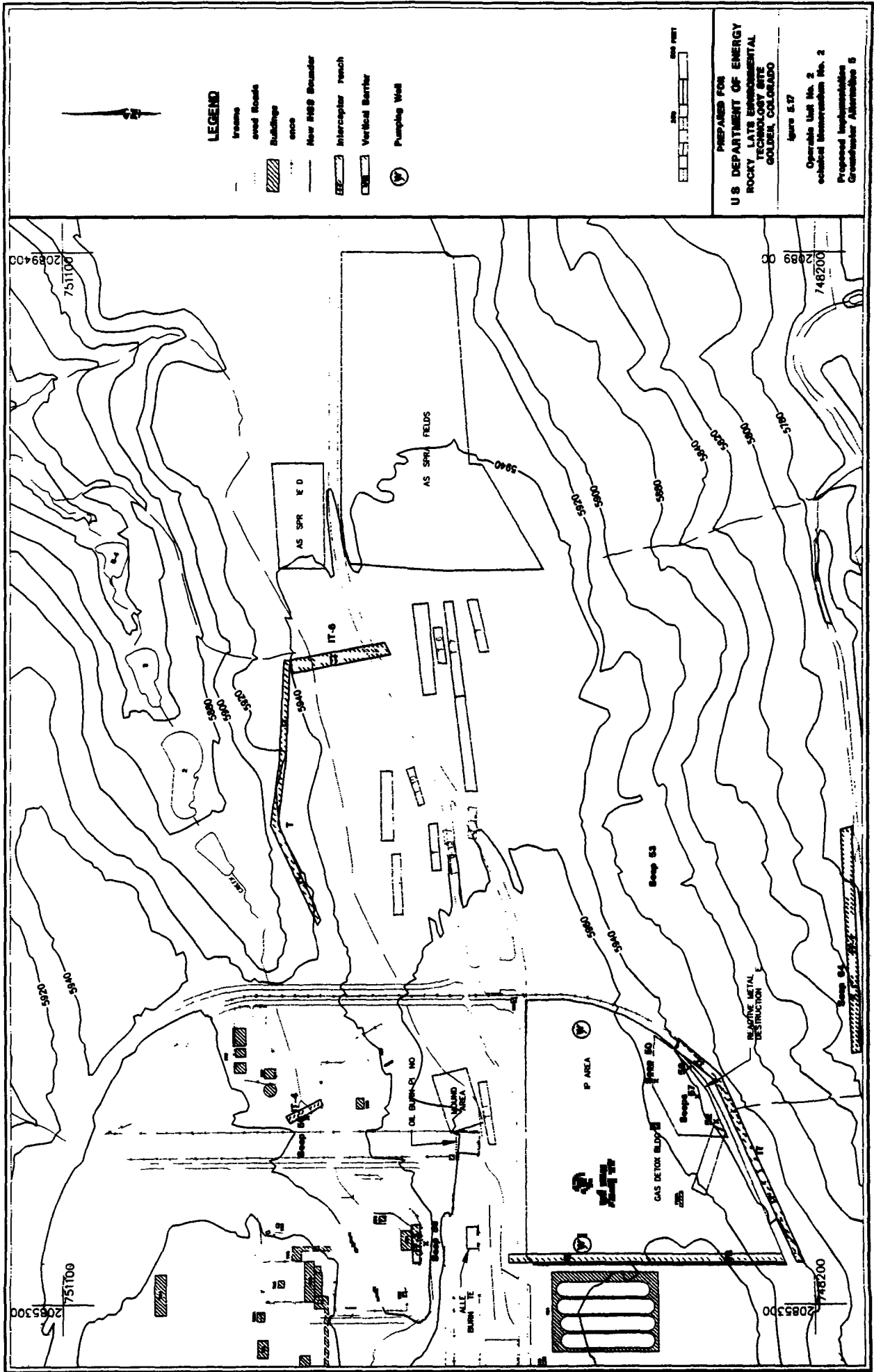


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Figure 5 14  
Operable Unit No 2  
Technical Memorandum No 2  
OU2 Groundwater Contamination Area  
(Radionuclides and VOCs)







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Figure 2.17

Operable Unit No. 2  
 Federal Memorandum No. 2  
 Proposed Implementation  
 Groundwater Alternative 5



# OU2 Remedial Alternatives Development Matrix

General Response Actions	Remediation Areas				
	Surface Soil Source	Subsurface Soil Source	Surface Soil Residual	Subsurface Soil Residual	UHSU Ground Water
No Further Action	a) No further action with long-term monitoring	a) No further action with long term monitoring	a) No further action with long term monitoring	a) No further action with long term monitoring	a) No further action with long term monitoring
Institutional Controls	a) Deed restrictions and general access restrictions	a) Deed restrictions and general access restrictions	a) Deed restrictions and general access restrictions	a) Deed restrictions and general access restrictions	a) Deed restrictions and general access restrictions
Containment	a) Cap in place	a) Cap in place b) Cap in place and install Barrier walls	a) Vegetative cover b) Cap in place	a) Cap in place	a) Barrier walls (only) b) Barrier walls (with localized dewatering)
In Situ Treatment	a) In Situ stabilization	a) Thermally enhanced soil vapor extraction enhanced bioremediation and cap b) Thermally enhanced oil vapor extraction enhanced bioremediation stabilization and cap c) Free liquid removal in situ stabilization cap d) In situ solidification (with pretreatment as necessary)	a) In Situ stabilization	a) Enhanced bioremediation b) Soil vapor extraction (ambient or thermally enhanced)	a) Enhanced bioremediation b) Air sparging c) Reaction wall
Removal	a) Excavation and disposal <sup>a</sup>	a) Excavation and disposal <sup>a</sup>	a) Excavation and disposal <sup>a</sup>	N/A	a) Collection and disposal b) Extraction (dewatering) and disposal c) Extraction treatment and re-injection
Ex Situ Treatment	a) Excavation and soil washing <sup>a</sup> b) Excavation ex situ stabilization, and return to excavation	a) Excavation, organics removal and soil washing <sup>a</sup> b) Excavation ex situ stabilization and return to excavation	a) Excavation and soil washing <sup>a</sup>	N/A	

<sup>a</sup> Disposal includes the evaluation of on-site disposal and off site disposal options (including treatment to meet waste acceptance criteria)

<sup>b</sup> Soils washing includes soils separation clean oil return fines processing waste management and disposal

**TABLE 2 1**  
**IHSSs ASSOCIATED WITH OU2**

IHSS	OU2 REMEDIATION AREAS <sup>a/</sup>			
	SOURCE AREAS FOR SURFACE SOIL CONTAMINATION	SOURCE AREAS FOR SUBSURFACE SOIL CONTAMINATION	RESIDUAL SURFACE SOIL CONTAMINATION	RESIDUAL SUBSURFACE SOIL CONTAMINATION
903 Pad Drum Storage Site (112)		X		X
903 Pad Lip Site (155)	X		X	X
East Spray Fields (216 2)			X	
East Spray Field (216 3)			X	
Gas Detoxification Site (183)			X	
Mound Site (113)		X	X	X
Oil Burn Pit No 2 Site (153)			X	
Pallet Burn Site (154)			X	
Reactive Metal Destruction Site (140)			X	
Trench T 1 (108)		X	X	X
Trench T 2 (109)		X	X	X
Trench T 3 (110)		X	X	X
Trench T-4 (111 1)		X	X	X
Trench T 5 (111 2)		X	X	X
Trench T-6 (111 3)		X	X	X
Trench T 7 (111 4)		X	X	X
Trench T 8 (111 5)		X	X	X
Trench T 9 (111 6)		X	X	X
Trench T 10 (111 7)		X	X	X
Trench T 11 (111 8)		X	X	X
Trench T 12		X	X	X
Trench T 13		X	X	X

<sup>a/</sup> Groundwater contamination in the UHSU occurs throughout OU2 and is non IHSS specific

TABLE  
PRELIMINARY REMEDIA ION LEVELS ROU SURFAC ONL

Chemical or Concen	Background Concentration (UTL 5%)	Minimum Detection Limit	Potential Specific AAAs/TECs	Programmatic Risk Based PRG												Maximum concentration Detected OU2 / mg/L	Selected Remediation agents at OU2	Does Remediation Constituent Need to be Considered?						
				Office Worker						Open Space Recreator														
				CT			Y			NC			Y						NC			Y		
				RM	CT	NC	RM	CT	NC	RM	CT	NC	RM	CT	NC				RM	CT	NC			
Aroclor 84 Imp/g	.00E 00 M	.00E 00 M	ABAs	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	No						
Aroclor 80 Imp/g	.00E 00 M	.00E 00 M	TECs	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	No						
Bis (2-ethylhexyl) phthalate Imp/g	.00E 00 M	.00E 00 M	ABAs	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	No						
Chromium Imp/g	SE	.00E 00	TECs	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	No						
Ammonium- bC/g	.00E 00	.00E 00	ABAs	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	No						
Phenanthrene-238/240 bC/g	.00E 00	.00E 00	TECs	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	No						

NOTES

- Open Space Recreator based on all RME and T values.  
 b/ Background concentration organic compounds assumed to be 1.  
 c/ TECA (see 40 CFR 1.1)  
 d/ RME PRG based on reasonable maximum exposure factors  
 e/ CT PRG based on carcinogenicity exposure factors  
 f/ NC PRG based on noncarcinogenic toxicity information  
 g/ PRG based on carcinogenic toxicity information  
 h/ RME and CT PRG values exceed 1000 ppm  
 i/ MDLs originate from the General Radiochemistry and Routine Analytical Services Protocol GAO, and EG&G, 9  
 j/ Maximum concentrations originate from analytical Memorandum No. 800E, 89 M  
 k/ Radiocesium value based on effluent worker exposure scenario only calculated utilizing the programmatic PRG  
 l/ equation and DOE Order 00 based on 100 mrem addition dose or members of the offsite public

TABLE 2.3  
PRELIMINARY REMEDIATION LEVELS FOR OU2 SUBSURFACE SOIL

Chemical Of Concern	Background Concentration (UTL 99%)	Minimum Detection Limit (l)	Pot tial Chem cal Specific ARARs/TBC	Programmatic Risk Based PRG					Maximum Concentration Detected (OU2) (l)	Standard Remediation Target (OU2) (l)	Does Remediation of Contaminant Need to be Considered?	
				Construction Work / Exposure Scenario			NC d/	CT /				
				ARARs	TBC	RME b/		C /				C /
Arsenic (mg/kg)	1.70E+01	2.00E+00	--	--	5.32E+02	7.09E+01	2.69E+03	3.58E+02	3.08E+01	7.09E+01	N	
Cadmium (mg/kg)	2.00E+00	1.00E+00	--	--	8.87E+02	>1.00E+06	1/4.48E+03	>1.00E+06	1.05E+01	8.87E+02	N	
Mercury (mg/kg)	2.10E+00	2.00E-01	--	--	5.32E+02	--	2.69E+03	--	1.14E+02	5.32E+02	N	
Trichloroethene (mg/kg)	0.00E+00	1.00E+00	--	--	1.77E+04	2.21E+03	8.96E+04	9.04E+03	1.30E+04	2.21E+03	Y	
Americium-241 (pCi/g)	2.00E-02	2.00E-02	--	7.09E+02/k	--	2.03E+02	--	5.37E+02	2.20E+01	7.95E+02	N	
Plutonium-239/240 (pCi/g)	2.50E-02	3.00E-02	--	1.56E+03/k	--	3.01E+02	--	1.51E+03	1.80E+02	1.57E+03	N	
Uranium-233/234 (pCi/g)	3.44E+00	3.00E-01	--	4.10E+04/k	--	4.11E+03	--	1.75E+04	1.92E+02	4.93E+04	No	
Uranium-235 (pCi/g)	1.53E-01	3.00E-01	--	2.05E+02/k	--	1.38E+01	--	1.73E+01	1.15E+01	2.55E+02	N	
Uranium-238 (pCi/g)	1.81E+00	3.00E-01	--	3.25E+03/k	--	6.42E+01	--	8.13E+01	1.13E+02	3.93E+03	N	

NOTES

- a/ Background concentrations for organic compounds are based on the maximum potential exposure factors  
b/ RME PRG based on reasonable maximum potential exposure factors  
c/ CT PRG based on central tendency exposure factors  
d/ NC PRG based on noncarcinogenic toxicity information  
e/ C PRG based on carcinogenic toxicity information  
f/ RME and CT PRG values exceed 10<sup>6</sup> parts per million  
g/ PRG values included daughter products  
h/ Modeling will be performed to verify if the remedial action objective is being protected from groundwater  
i/ MDLs originate from the General Radiochemistry and Routine Analytical Service Protocol (EG&G 1991) and EG&G 1991b)  
j/ Maximum concentrations originate from Technical Memorandum N 9 (DOE 1991b)  
k/ Radionuclide value is based on construction worker exposure scenario only. Calculated utilizing the programmatic PRG question and DOE Order 5400.5 based on 100 mrem addition dose for members of the public

T BLE 4  
PRELIMINARY REMEDIATION LEVELS FOR OU2 UHSU GROUNDWATER

Chemical of Concern (Units as Indicated)	Background Concentration (UT <sub>TM</sub> )	Minimum Detection Limit	Potential Chemical-Specific ARARs/TBCs		Maximum Concentration Detected at OU2	Selected Remediation Targets for OU2	Does Remediation of Contaminant Need to be Considered?
			ARARs	TBCs			
Carbon Tetrachloride (ug/L)	0.00E 00	5.00E 00	1.00E 00 5.00E 00	—	2.00E 04	5.00E 00	Yes
Chloroform (ug/L)	0.00E 00	5.00E 00	6.00E 00 1.00E 02	—	3.90E 04	6.00E 00	Yes
1,1-Dichloroethene (g/L)	0.00E 00	5.00E 00	0.0E 00	—	8.0E 02	0.0E 00	cs
Methylene Chloride (ug/L)	0.00E 00	5.00E 00	5.00E 00	—	3.50E 04	5.00E 00	Yes
Tetrachloroethene (ug/L)	0.00E 00	5.00E 00	5.00E 00	—	1.40E 04	5.00E 00	Yes
Trichloroethene (ug/L)	0.00E 00	5.00E 00	5.00E 00 <sup>ND</sup>	—	1.50E 05	5.00E 00	Yes
Vinyl Chloride (ug/L)	0.00E 00	1.00E 01	0.0E 00	—	8.60E 02	2.00E 00	Yes
Americium-241 (pCi/L)	3.70E-2	1.00E-02	—	3.00E 01	4.65E 01	3.00E 0	Yes
Plutonium-239/240 (pCi/L)	6.40E-02	1.00E-02	—	3.00E 01	3.55E 02	3.00E 0	Yes

**NOTES:**

All federal values are based on Maximum Contaminant Levels (40 CFR 141 and 142). Value for chloroform based on the sum of all isohexanes (c bromodichloromethane, dibromochloromethane, bromoform, and chloroform).  
Background concentration for organic compounds assumed as the zero.  
Colorado Statewide Standard for Groundwater (5 CCR 1002-8, Section 3.11). All organic values are interim standards.  
Derived Concentration Guidelines from DOE Order 5400.5 Chapter III based on 100 year radiation dose for members of the offsite public. Values are based on groundwater pathway only.  
MDLs originate from the General Radiocesium and Routine Analytical Services Protocol (EG&G 1991) and EG&G 1991b).  
Maximum concentrations originate from Technical Memorandum No. 9 (DOE 1994b).

**TABLE 2 5**  
**IHSSs THAT CONTAIN CONTAMINANTS OF CONCERN**  
**GREATER THAN SELECTED REMEDIATION TARGETS**

IHSS	OU2 REMEDIATION AREAS <sup>a/</sup>			
	SOURCE AREAS FOR SURFACE SOIL CONTAMINATION	SOURCE AREAS FOR SUBSURFACE SOIL CONTAMINATION	RESIDUAL SURFACE SOIL CONTAMINATION	RESIDUAL SUBSURFACE SOIL CONTAMINATION
903 Pad Drum Storage Site (112)		X		
903 Pad Lip Site (155)	X		X <sup>b/</sup>	
East Spray Fields (216 2)				
East Spray Field (216 3)				
Gas Detoxification Site (183)				
Mound Site (113)		X		
Oil Burn Pit No 2 Site (153)				
Pallet Burn Site (154)				
Reactive Metal Destruction Site (140)				
Trench T 1 (108)		X		
Trench T 2 (109)		X		
Trench T 3 (110)		X		X
Trench T-4 (111 1)		X		
Trench T 5 (111 2)		X		
Trench T-6 (111 3)		X		
Trench T 7 (111 4)		X		
Trench T 8 (111 5)		X		
Trench T 9 (111 6)		X		
Trench T 10 (111 7)		X		
Trench T 11 (111 8)		X		
Trench T 12		X		
Trench T 13		X		

<sup>a/</sup> Groundwater contamination in the UHSU occurs throughout OU2 and is non IHSS specific

<sup>b/</sup> Includes surrounding areas of the IHSS with concentrations of contamination that exceed OU2 remediation target level

**TABLE 4 1**  
**SELECTED REPRESENTATIVE PROCESS OPTIONS**  
**FOR SURFACE SOILS**

<u>SURFACE SOIL GENERAL RESPONSE ACTION</u>	<u>REMEDIAL TECHNOLOGY</u>	<u>REPRESENTATIVE PROCESS OPTION</u>
No Further Action (NFA)	None	Not Applicable
Institutional Actions	Access Restrictions Land Use Restrictions Monitoring	Fencing Security Etc Deed Restrictions Fugitive Dust Monitoring
Containment	Horizontal Barriers	Cover
Removal	Excavation	Soil Excavation
	Short Distance Transport Long Distance Transport	Conveyor System Truck/Rail Hauling
	Offsite Disposal Onsite Disposal	Landfill/TSD Facility Permitted Landfill
<i>In Situ</i> Treatment	Solidification/Stabilization	Solidification/Stabilization
<i>Ex Situ</i> Treatment	Chemical/Physical Treatment Solidification/Stabilization	Soil Washing Stabilization Vitrification

**TABLE 4 2**  
**SELECTED REPRESENTATIVE PROCESS OPTIONS**  
**FOR SUBSURFACE SOILS**

<b>SUBSURFACE SOIL GENERAL <u>RESPONSE ACTION</u></b>	<b><u>REMEDIAL TECHNOLOGY</u></b>	<b><u>REPRESENTATIVE PROCESS OPTION</u></b>
No Further Action (NFA)	None	Not Applicable
Institutional Controls	Access Restrictions Land Use Restrictions Monitoring	Fencing Security Etc Deed Restrictions Vadose Zone Monitoring
Containment	Vertical Barriers Horizontal Barriers	Slurry Wall Cover
Removal	Mechanical Excavation	Soil Excavation
	Short Distance Transport Long Distance Transport	Conveyer System Truck/Rail Hauling
	Offsite Disposal Onsite Disposal	Landfill/TSD Facility Permitted Landfill
<i>In Situ</i> Treatment	Biological Chemical/Physical Treatment Solidification/Stabilization	Enhanced Bioremediation Soil Vapor Extraction Stabilization Vitrification
	Thermal Treatment	Thermally Enhanced Soil Vapor Extraction
<i>Ex Situ</i> Treatment	Chemical/Physical Treatment Solidification/Stabilization	Soil Washing Encapsulation Vitrification
	Thermal Treatment	Low Temperature Thermal Desorption Incineration

**TABLE 4 3**  
**SELECTED REPRESENTATIVE PROCESS OPTIONS**  
**FOR GROUNDWATER**

<b><u>GROUNDWATER GENERAL RESPONSE ACTION</u></b>	<b><u>REMEDIAL TECHNOLOGY</u></b>	<b><u>REPRESENTATIVE PROCESS OPTION</u></b>
No Further Action (NFA)	Intrinsic Remediation	Groundwater Monitoring
Institutional Controls	Access Controls Land Use Restrictions Intrinsic Remediation	Fencing Security Etc Deed Restrictions Groundwater Monitoring
Containment	Surface Controls Groundwater Controls Vertical Barriers Horizontal Barriers	Revegetation Interceptor Trenches Cutoff Wall Cover
Removal	Groundwater Extraction Groundwater Transport Disposal	Interceptor Trenches Truck/Rail Hauling RFETS Sewage Treatment Plant
<i>In Situ</i> Treatment	Enhanced Bioremediation  Chemical/Physical Treatment  Thermal	Enhanced Aerobic Bioremediation Enhanced Anaerobic Bioremediation Air Sparging/SVE Passive Treatment Wall  Thermally Enhanced Soil Vapor Extraction
<i>Ex Situ</i> Treatment	Chemical/Physical Treatment	Onsite Water Treatment Plant

**TABLE 6 1**  
**POTENTIAL LOCATION AND ACTION SPECIFIC ARARs/TBCs FOR**  
**SOURCE AREAS FOR SURFACE SOIL CONTAMINATION**

ARAR/TBC CITATION	REQUIREMENT DESCRIPTION	ALTERNATIVE						
		NFA	Institutional Controls	Cap in Place	In Situ Stabilization/Solidification	Excavate Dispose	Excavate Soil Washing	Excavate Ex Situ Solidification/Stabilization Return
16 USC §§ 469 and 470 36 CFR 65 296 and 800 43 CFR 3 and 7 CRS 24 80-401 to 410	Historic and Archeological Preservation <sup>a/</sup>	X	X	X	X	X	X	X
16 USC § 661 et seq	Fish and Wildlife Coordination Act	X	X	X	X	X	X	X
16 USC § 668	Eagle Protection Acts	X	X	X	X	X	X	X
16 USC § 701 715 50 CFR 10	Migratory Bird Treaty	X	X	X	X	X	X	X
16 USC § 1531 50 CFR 402 CRS 33 2 101 to 33 2 107	Evaluate Federal Projects for Potential Impact to Endangered or Threatened Species or Critical Habitats	X	X	X	X	X	X	X
50 CFR 17	Endangered and Threatened Wildlife and Plants	X	X	X	X	X	X	X
50 CFR 424	Listing Endangered and Threatened Species and Designating Critical Habitat	X	X	X	X	X	X	X
33 USC § 1344 10 CFR 1022	Evaluate Federal Projects for Potential Floodplain and Wetland Impacts <sup>a/</sup>	X	X	X	X	X	X	X
Executive Order 11988	Floodplain Management Federal Facilities	X	X	X	X	X	X	X
Executive Order 11990	Protection of Wetlands Federal Facilities	X	X	X	X	X	X	X
10 CFR 834 (Proposed)	DOE Radiation Protection Requirements for Public Health and the Environment <sup>a/</sup>	X	X	X	X	X	X	X
DOE Order 5400 5 Chapter IV	Residual Radioactive Material in Soil	X	X	X	X	X	X	X

**TABLE 6 1 (Continued)**  
**POTENTIAL LOCATION AND ACTION SPECIFIC ARARs/TBCs FOR**  
**SOURCE AREAS FOR SURFACE SOIL CONTAMINATION**

ARAR/TBC CITATION	REQUIREMENT DESCRIPTION	ALTERNATIVE						
		NFA	Institutional Controls	Cap in Place	In Situ Stabilization/Solidification	Excavate Dispose	Excavate Soil Washing	Excavate Ex Situ Solidification/Stabilization/Return
DOE Order 5820 2A Chapter III	Low Level Radioactive Waste Management	X	X	X	X	X	X	X
10 CFR 835	Occupational Radiation Protection Standards <sup>d/</sup>		X	X	X	X	X	X
DOE Order 5480 11 Section 9	Worker Protection Requirements <sup>d/</sup>	-	X	X	X	X	X	X
29 USC §§ 657 and 667 29 CFR 1910	Occupational Health Standards for General Construction Activities <sup>u/</sup>		X	X	X	X	X	X
29 USC § 668 DOE Order 5483 1A 29 CFR 1926	NESHAP Radionuclide Emissions	X	X	X	X	X	X	X
40 CFR 61 Subpart H 10 CFR 834 (Proposed)	Fugitive Particulate Emissions <sup>u/</sup>	-	-	X	X	X	X	X
5 CCR 1001 Regulation 1	NPDES Stormwater Management Requirements	X	X	X	X	X	X	X
40 CFR 122 26 5 CCR 1002 3 122 26	Hazardous Waste Determinations	X	X	X	X	X	X	X
40 CFR 262 11 6 CCR 1007 3 262 11	Packaging and Transportation Requirements for Radioactive Materials <sup>w/</sup>				-	X	X	
DOE Order 5480 3	Natural Phenomena Hazard Mitigation	X	X	X	X	X	X	X
DOE Order 5480 28								

**TABLE 6 2**  
**POTENTIAL LOCATION AND ACTION SPECIFIC ARARs/TBCs FOR**  
**RESIDUAL SURFACE SOIL CONTAMINATION**

ARAR/TBC CITATION	REQUIREMENT DESCRIPTION	ALTERNATIVE						
		NFA	Institutional Controls	Vegetative Cover	Cap in Place	In Situ Stabilization/Solidification	Excavate Dispose	Excavate Ex Situ Soil Washing
16 USC §§ 469 and 470 36 CFR 65 296 and 800 43 CFR 3 and 7 CRS 24 80-401 to 410	Historic and Archeological Preservation <sup>a/</sup>	X	X	X	X	X	X	X
16 USC § 661 et seq	Fish and Wildlife Coordination Act	X	X	X	X	X	X	X
16 USC § 668	Eagle Protection Acts	X	X	X	X	X	X	X
16 USC § 701 715 50 CFR 10	Migratory Bird Treaty	X	X	X	X	X	X	X
16 USC § 1531 50 CFR 402 CRS 33 2 101 to 33 2 107	Evaluate Federal Projects for Potential Impact to Endangered or Threatened Species or Critical Habitats	X	X	X	X	X	X	X
50 CFR 17	Endangered and Threatened Wildlife and Plants	X	X	X	X	X	X	X
50 CFR 424	Listing Endangered and Threatened Species and Designating Critical Habitat	X	X	X	X	X	X	X
33 USC § 1344 10 CFR 1022	Evaluate Federal Projects for Potential Floodplain and Wetland Impacts <sup>b/</sup>	X	X	X	X	X	X	X
Executive Order 11988	Floodplain Management Federal Facilities	X	X	X	X	X	X	X
Executive Order 11990	Protection of Wetlands Federal Facilities	X	X	X	X	X	X	X
10 CFR 834 (Proposed)	DOE Radiation Protection Requirements for Public Health and the Environment <sup>c/</sup>	X	X	X	X	X	X	X
DOE Order 5400 5 Chapter IV	Residual Radioactive Material in Soil	X	X	X	X	X	X	X
6 CCR 1007 1 Part 4	Rules and Regulations Pertaining to Radiation Control	X	X	X	X	X	X	X
DOE Order 5820 2A Chapter III	Low Level Radioactive Waste Management	X	X	X	X	X	X	X

**TABLE 6 2 (Continued)**  
**POTENTIAL LOCATION AND ACTION SPECIFIC ARARs/TBCs FOR**  
**RESIDUAL SURFACE SOIL CONTAMINATION**

ARAR/TBC CITATION	REQUIREMENT DESCRIPTION	ALTERNATIVE						
		NFA	Institutional Controls	Vegetative Cover	Cap in Place	In Situ Stabilization/Solidification	Excavate Dispose	Excavate Ex Situ Soil Washing
10 CFR 835 DOE Order 5480 11 Section 9	Occupational Radiation Protection Standards <sup>u</sup>		X	X	X	X	X	X
29 USC §§ 657 and 667 29 CFR 1910	Worker Protection Requirements <sup>u</sup>		X	X	X	X	X	X
29 USC § 668 DOE Order 5483 1A 29 CFR 1926	Occupational Health Standards for General Construction Activities <sup>u</sup>	-	X	X	X	X	X	X
40 CFR 61 Subpart H 10 CFR 834 (Proposed)	NESHAP Radionuclide Emissions	X	X	X	X	X	X	X
5 CCR 1001 Regulation 1	Fugitive Particulate Emissions <sup>u</sup>	-	-	X	X	X	X	X
40 CFR 122 26 5 CCR 1002 3 122 26	NPDES Stormwater Management Requirements	X	X	X	X	X	X	X
40 CFR 262 11 6 CCR 1007 3 262 11	Hazardous Waste Determinations	X	X	X	X	X	X	X
DOE Order 5480 3	Packaging and Transportation Requirements for Radioactive Materials <sup>u</sup>	-	--	-			X	X
DOE Order 5480 28	Natural Phenomena Hazard Mitigation	X	X	X	X	X	X	X

**TABLE 6 3**  
**POTENTIAL LOCATION AND ACTION SPECIFIC ARARs/TBCs FOR**  
**RESIDUAL SUBSURFACE SOIL CONTAMINATION**

ARAR/TBC CITATION	REQUIREMENT DESCRIPTION	ALTERNATIVE	
		NFA	In Situ SVE
16 USC §§ 469 and 470 36 CFR 65 296 and 800 43 CFR 3 and 7 CRS 24 80-401 to 410	Historic and Archeological Preservation <sup>a/</sup>	X	X
16 USC § 661 et seq	Fish and Wildlife Coordination Act	X	X
16 USC § 668	Eagle Protection Acts	X	X
16 USC § 701 715 50 CFR 10	Migratory Bird Treaty	X	X
16 USC § 1531 50 CFR 402 CRS 33 2 101 to 33 2 107	Evaluate Federal Projects for Potential Impact to Endangered or Threatened Species or Critical Habitats	X	X
50 CFR 17	Endangered and Threatened Wildlife and Plants	X	X
50 CFR 424	Listing Endangered and Threatened Species and Designating Critical Habitat	X	X
33 USC § 1344 10 CFR 1022	Evaluate Federal Projects for Potential Floodplain and Wetland Impacts <sup>w/</sup>	X	X
Executive Order 11988	Floodplain Management Federal Facilities	X	X
Executive Order 11990	Protection of Wetlands Federal Facilities	X	X
10 CFR 834 (Proposed)	DOE Radiation Protection Requirements for Public Health and the Environment <sup>d/</sup>	X	X
DOE Order 5400 5 Chapter IV	Residual Radioactive Material in Soil	X	X
DOE Order 5820 2A Chapter III	Low Level Radioactive Waste Management	X	X
10 CFR 835 DOE Order 5480 11 Section 9	Occupational Radiation Protection Standards <sup>d/</sup>		X
29 USC §§ 657 and 667 29 CFR 1910 120	Worker Protection Requirements for Hazardous Waste/Remediation Operations <sup>d/</sup>		X

**TABLE 6 3 (Continued)**  
**POTENTIAL LOCATION AND ACTION SPECIFIC ARARs/TBCs FOR**  
**RESIDUAL SUBSURFACE SOIL CONTAMINATION**

ARAR/TBC CITATION	REQUIREMENT DESCRIPTION	ALTERNATIVE	
		NFA	In Situ SVE
29 USC § 668 DOE Order 5483 1A 29 CFR 1926	Occupational Health Standards for General Construction Activities <sup>v</sup>		X
40 CFR 61 Subpart H 10 CFR 834 (Proposed)	NESHAP Radionuclide Emissions <sup>v</sup>	X	X
40 CFR 122 26 5 CCR 1002 3 122 26	NPDES Stormwater Management Requirements	X	X
6 CCR 1007 2 Part 2	Siting Requirements for Hazardous Waste Disposal Sites <sup>v</sup>	X	X
40 CFR 261 6 CCR 1007 3 261	Identification and Listing of Hazardous Waste	X	X
40 CFR 262 11 6 CCR 1007 3 262 11	Hazardous Waste Determinations	X	X
40 CFR 262 Subparts B C and D 6 CCR 1007 3 262 Subparts B C and D	Generator Requirements for Offsite Transport of Hazardous Waste <sup>w</sup>		X
40 CFR 264 Subpart B 6 CCR 1007 3 264 Subpart B	General Standards for Hazardous Waste Facilities <sup>v</sup>		X
40 CFR 264 Subpart C and D 6 CCR 1007 3 264 Subpart C and D	Preparedness and Prevention and Emergency Procedures for Hazardous Waste Facilities <sup>v</sup>	-	X
40 CFR 264 Subpart E 6 CCR 1007 3 264 Subpart E	Manifest System Recordkeeping and Reporting	-	X
40 CFR 264 Subpart F 6 CCR 1007 3 264 Subpart F	Groundwater Protection and Monitoring <sup>v</sup>		X
40 CFR 264 Subpart G 6 CCR 1007 3 264 Subpart G	Closure and Post Closure		X

**TABLE 6 3 (Continued)**

**POTENTIAL LOCATION AND ACTION SPECIFIC ARARs/TBCs FOR  
RESIDUAL SUBSURFACE SOIL CONTAMINATION**

ARAR/TBC CITATION	REQUIREMENT DESCRIPTION	ALTERNATIVE	
		NFA	In Situ SVE
40 CFR 264 Subpart I 6 CCR 1007.3.264 Subpart I	Use and Management of Containers		X
40 CFR 267	Identification and Listing of Hazardous Waste	X	X
42 USC § 6924 40 CFR 268 Subpart A to D 6 CCR 1007.3.268 Subpart A to D	Land Disposal Restrictions and Treatment Standards <sup>m/</sup>	--	X
40 CFR 268 Subpart E 6 CCR 1007.3.268 Subpart E	Prohibition on Storage of Restricted Waste		X
49 CFR 172 Parts B to F 49 CFR 173 Parts B to O 49 CFR 177	Offsite Transport of Hazardous Waste <sup>n/</sup>		X
DOE Order 5480.28	Natural Phenomena Hazard Mitigation	X	X

**TABLE 6 4**  
**POTENTIAL LOCATION AND ACTION SPECIFIC ARARs/TBCs FOR**  
**UHSU GROUNDWATER**

ARAR/TBC CITATION	REQUIREMENT DESCRIPTION	ALTERNATIVE				
		NFA	Institutional Controls	Containment	In Situ Treatment	Ex Situ Treatment
16 USC §§ 469 and 470 36 CFR 65 296 and 800 43 CFR 3 and 7 CRS 24 80-401 to 410	Historic and Archeological Preservation <sup>a/</sup>	X	X	X	X	X
16 USC § 661 et seq	Fish and Wildlife Coordination Act	X	X	X	X	X
16 USC § 668	Eagle Protection Acts	X	X	X	X	X
16 USC § 701 715 50 CFR 10	Migratory Bird Treaty	X	X	X	X	X
16 USC § 1531 50 CFR 402 CRS 33 2 101 to 33 2 107	Evaluate Federal Projects for Potential Impact to Endangered or Threatened Species or Critical Habitats	X	X	X	X	X
50 CFR 17	Endangered and Threatened Wildlife and Plants	X	X	X	X	X
50 CFR 424	Listing Endangered and Threatened Species and Designating Critical Habitat	X	X	X	X	X
33 USC § 1344 10 CFR 1022	Evaluate Federal Projects for Potential Floodplain and Wetland Impacts <sup>b/</sup>	X	X	X	X	X
Executive Order 11988	Floodplain Management Federal Facilities	X	X	X	X	X
Executive Order 11990	Protection of Wetlands Federal Facilities	X	X	X	X	X
10 CFR 834 (Proposed)	DOE Radiation Protection Requirements for Public Health and the Environment <sup>c/</sup>	X	X	X	X	X
10 CFR 835 DOE Order 5480 11 Section 9	Occupational Radiation Protection Standards <sup>d/</sup>	-	X	X	X	X
29 USC §§ 657 and 667 29 CFR 1910 120	Worker Protection Requirements for Hazardous Waste/Remediation Operations <sup>e/</sup>	-	X	X	X	X

**TABLE 6 4 (Continued)**  
**POTENTIAL LOCATION AND ACTION-SPECIFIC ARARs/TBCs FOR**  
**UHSU GROUNDWATER CONTAMINATION**

ARAR/TBC CITATION	REQUIREMENT DESCRIPTION	ALTERNATIVE				
		NFA	Institutional Controls	Containment	In Situ Treatment	Ex Situ Treatment
29 USC § 668 DOE Order 5483 1A 29 CFR 1926	Occupational Health Standards for General Construction Activities <sup>v</sup>	-	X	X	X	X
40 CFR 61 Subpart H 10 CFR 834 (Proposed)	NESHAP Radionuclide Emissions	X	X	X	X	X
5 CCR 1001 Regulation 1 III D	Fugitive Particulate Emissions <sup>v</sup>			X	X	X
40 CFR 122 26 5 CCR 1002 3 122 26	NPDES Stormwater Management Requirements	X	X	X	X	X
40 CFR 261 6 CCR 1007 3 261	Identification and Listing of Hazardous Waste	X	X	X	X	X
40 CFR 262 11 6 CCR 1007 3 262 11	Hazardous Waste Determinations	X	X	X	X	X
40 CFR 262 Subparts B C and D 6 CCR 1007 3 262 Subparts B C and D	Generator Requirements for the Offsite Transport of Hazardous Waste <sup>v</sup>		-	X	X	X
40 CFR 264 Subpart F 6 CCR 1007 3 264 Subpart F	Groundwater Protection and Monitoring <sup>v</sup>	X	X	X	X	X
40 CFR 264 Subpart G 6 CCR 1007 3 264 Subpart G	Closure and Post Closure Care	-	-			X
40 CFR 264/265 Subpart I 6 CCR 1007 3 264/265 Subpart I	Use and Management of Containers		--	X	X	X
42 USC § 6924 40 CFR 268 Subpart A to D 6 CCR 1007 3 268 Subpart A to D	Land Disposal Restrictions and Treatment Standards <sup>uv</sup>	-	-	X	X	X
40 CFR 268 Subpart E 6 CCR 1007 3 268 Subpart E	Prohibition on Storage of Restricted Waste		-	X	X	X

**TABLE 6 4 (Continued)**  
**POTENTIAL LOCATION AND ACTION SPECIFIC ARARs/TBCs FOR**  
**UHSU GROUNDWATER CONTAMINATION**

ARAR/TBC CITATION	REQUIREMENT DESCRIPTION	ALTERNATIVE				
		NFA	Institutional Controls	Containment	In Situ Treatment	Ex Situ Treatment
49 CFR 172 Parts B to F 49 CFR 173 Parts B to O 49 CFR 177	Offsite Transport of Hazardous Waste <sup>m</sup>			X	X	X
DOE Order 5480 3	Packaging and Transportation Requirements for Radioactive Materials <sup>m</sup>		-	X	X	X
DOE Order 5480 28	Natural Phenomena Hazard Mitigation	X	X	X	X	X

## NOTES

- a/ Although no historic or archeological sites are expected to be impacted all federal actions are required to be assessed
- b/ Although no wetlands are expected to be impacted all federal actions are required to be assessed
- c/ This regulation is proposed by the DOE to control radiation exposures for the protection of public health and the environment Although NRC also has similar protection standards promulgated under 10 CFR 20.1301 the DOE regulation is identified as an ARAR for compliance purposes since the DOE regulation is consistent with the NRC standards and will be applicable to RFETS when promulgated
- d/ Although occupational worker standards are not considered to be ARARs/TBCs the citation to the DOE Radiation Protection Program is being provided for completeness and to ensure that these protection requirements are not overlooked when preparing the implementation plans for the selected alternative
- e/ Although OSHA standards are not considered ARARs (see 55 FR 8680) 40 CFR 300.150 specifically requires that all response actions under the NCP maintain worker safety and health as specified under 29 CFR 1910.120 This regulation is being listed for completeness and to ensure that these protection requirements are not overlooked when preparing the implementation plans for the selected alternative
- f/ Although OSHA standards are not considered ARARs (see 55 FR 8680) OSHA requirements would apply on their own merit These OSHA standards apply to federal facilities as required by the Occupational Safety and Health Act [29 USC § 668] and Executive Order 12196 however they are not independently enforced by OSHA These occupational safety requirements are adopted and implemented under DOE Order 5483.1A This regulation is being listed for completeness and to ensure that these protection requirements are not overlooked when preparing the implementation plans for the selected alternative
- g/ This standard would involve the control of fugitive particulates during regrading and/or excavation activities
- h/ Record keeping requirements are not normally considered to be ARARs since they are procedural/administrative requirements However offsite response actions must comply with all applicable regulations both substantive and procedural/administrative The generator record keeping and reporting requirements would only be applicable in the case where radioactive waste is shipped offsite
- i/ CDPHE claims that a hazardous waste disposal site is developed in the event that hazardous waste remains in place following the completion of closure activities Pursuant to Part 18 of the IAG the DOE does not have to comply with the procedural aspects of the siting regulations to obtain a Certificate of Designation for the onsite response action however these alternatives must comply with the substantive requirements of this regulation
- j/ These requirements would only be applicable should a new hazardous waste storage or treatment facility be constructed as part of the alternative These requirements would address the operation of the storage and treatment facility only Should waste materials be stored or treated within existing onsite facilities management of the waste will be the responsibility of the storage/treatment facility custodian
- k/ Post-closure groundwater monitoring is required for the dirty closure of the landfill unless the owner/operator can demonstrate that groundwater monitoring is not necessary

Notes (Continued)

- l/ Interim status operational requirements apply to hazardous waste facilities until they are certified as being closed. Security training and inspection programs will need to be maintained and revised if necessary to ensure that public health and the environment are adequately protected during the closure activities.
- m/ In addition to complying with the required treatment standards for the land disposal of any designated hazardous waste offsite shipments will need to be certified as required.

**APPENDIX A**

**DESCRIPTION OF SOIL TECHNOLOGIES AND PROCESS OPTIONS  
PASSING THE TECHNICAL IMPLEMENTABILITY SCREEN**

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## **DESCRIPTION OF SOIL TECHNOLOGIES AND PROCESS OPTIONS PASSING THE TECHNICAL IMPLEMENTABILITY SCREEN**

This appendix provides a description of the technologies and process options that have passed the technical implementability screen and are being considered for remediation of contaminated soil at RFETS. The technologies included in this appendix cover the range of options and approaches available to treat contaminated soil or otherwise protect human health and the environment. These technologies alone or in combination have been considered in the development of alternatives to satisfy the remedial action objectives. EPA guidance documents, engineering reference materials, technical journals, periodicals, and reference data bases were used to prepare these technology descriptions.

The technologies are organized in general by general response action, technology type, and process option. The following general response actions are: no action, institutional actions, containment, removal, transport, storage, and disposal, *in situ* treatment, and *ex situ* treatment.

### **A 1 NO FURTHER ACTION**

The no action option provides a baseline exposure risk scenario for comparison with the risks associated with implementation of other technology types. No action means no response to potential soil contamination and no interruption of potential human health and environmental exposure pathways. Although nothing is implemented to address soil contamination under no action, natural processes such as dilution, volatilization, biodegradation, adsorption, and chemical reactions may occur. These processes are collectively referred to as natural attenuation, and over time may reduce contaminant concentrations. Contaminants that may be degraded, removed, or reduced as a result of natural attenuation include non-halogenated volatile and semivolatile organics and petroleum hydrocarbons. Other compounds such as halogenated volatiles and semivolatiles, pesticides, and inorganics may also naturally attenuate, but not as effectively.

The following factors may limit the applicability and effectiveness of the process:

No action and natural attenuation should be used only in low risk situations, and

No action may require periodic soil, surface water, and groundwater monitoring (EPA 1988) to determine if any changes have taken place in short-term and long-term risks.

### **A 2 INSTITUTIONAL CONTROLS**

Institutional controls reduce exposure to site contaminants through administrative actions and access restrictions. Administrative actions include land access and use restrictions and monitoring of conditions at the site. The intent of access restrictions is to interrupt exposure pathways. Access restrictions include barriers, fencing, and warning signs.

Institutional controls may be appropriate for sites where the potential for exposure is minimal or where baseline risks are determined to be low. However, institutional controls may also be selected for highly contaminated sites where the risks to workers or community during remediation would exceed the present risks at the site. In this case, institutional controls could include site access restrictions.

As indicated above, institutional controls may be combined with other response actions to satisfy remedial action objectives. For example, if a site is remediated through containment or treatment, institutional controls such as deed restrictions or access restrictions may be implemented during, as well as after, the site is remediated.

## **A 2 1        Access Restrictions**

Access restrictions reduce potential exposures by limiting access to contaminated areas. Such restrictions include warning signs, fences, and other physical barriers, and can also include security systems such as guards, lighting, and alarms. The most common access restriction applicable to humans is fencing.

The following factors may limit the applicability and effectiveness of the process:

Access restrictions may have to be expanded if contaminants migrate, and

It is difficult to establish vertical access restrictions.

### **A 2 1 1        Fencing, Security**

Exposure to contaminants would be reduced or eliminated by installing a fence around the entire site. Long-term security would be provided to ensure that the public does not enter into the restricted area. Monitoring would be needed to ensure that the contaminants are not migrating outside the fenced area. If contamination migration occurred, the fenced area may need to be expanded to ensure protection of the public.

## **A 2 2        Land Use Restrictions**

Exposure to contaminants may be reduced or eliminated through land use restrictions. Land use restrictions may be incorporated in deeds or zoning requirements. Often, deed and zoning restrictions must be considered together because deed restrictions indicate what cannot be done, and zoning restrictions indicate what can be done. Before deed restrictions can be implemented, a comprehensive title search would be needed to verify Fee Simple ownership (i.e., mineral, water, and other inherent rights) of the land.

## **A 2 2 1      Deed Restrictions**

Exposure to contaminants may be reduced or eliminated by adding restrictions to the property deed that limit the future land use. For example, residential or commercial construction in contaminated areas could be prohibited by defining those areas and adding an appropriate stipulation in the property deed. The contaminants would not be removed but may be reduced over time by natural attenuation.

The following factors may limit the applicability and effectiveness of the process:

The mineral water or other inherent rights must be purchased if they are owned by another party and

Potential present and future legal challenges may cause difficulties

## **A 2 2 2      Zoning Restrictions**

Exposure to contaminants may be reduced or eliminated by restricting future land use through zoning ordinances. Zoning restrictions would restrict development or use of the entire property rather than just the contaminated areas. Again, the contaminants would not be removed but may be reduced over time by natural attenuation.

The following factors may limit the applicability and effectiveness of the process:

Zoning restrictions may be changed by public and institutional decree at any time and

Potential present and future legal challenges may cause difficulties

## **A 2 3      Monitoring**

Monitoring of surface water, groundwater, vadose zone moisture, or fugitive dust may be incorporated into a remedial action alternative to evaluate site conditions before, during, and after remediation. Monitoring involves periodic sampling and analysis to determine if surface water, groundwater, vadose zone, or fugitive dust contaminants have degraded or migrated. Monitoring does not reduce contaminant toxicity, mobility, or volume. Consultants and laboratories that conduct surface water, groundwater, vadose zone, and fugitive dust monitoring are readily available.

The following factors may limit the applicability and effectiveness of the process:

Stratification of contaminants in stagnant waters must be considered and

Proper location and installation of the monitoring wells can be difficult and should be based on all available contaminant data as well as on geologic and hydrogeologic data

#### **A 2 3 1      Groundwater Monitoring**

Site specific characteristics that influence the placement of monitoring wells include the nature of the aquifer (e g artesian) characteristics of potential leachate and groundwater depth flow rates and direction of flow Based on assumptions and data about the characteristics of the site approximate permeability of soils in the zone of aeration and directions and velocities of groundwater flow the maximum probable areal extent of contaminant migration can be estimated as a basis for establishing the position of monitoring wells

Proper location and installation of monitoring wells are essential to a monitoring program A minimum of four groundwater monitoring wells are typically installed at a hazardous waste site one upgradient well and three downgradient wells However site hydrogeology is often too complex for only four wells to provide adequate detection of groundwater contamination

Upgradient wells are placed beyond the upgradient extent of contamination At least three downgradient wells are located to ensure that releases of hazardous waste or hazardous waste constituents from the hazardous waste management unit(s) to the uppermost aquifer will be quickly detected The specific number of wells to be included in a detection system depends on the horizontal spacing between well locations and the vertical sampling interval of individual wells

#### **A 2 3 2      Vadose Zone Monitoring**

Monitoring of the vadose zone (i e the unsaturated zone) of soil beneath a hazardous waste site is currently not required by federal regulations However vadose zone monitoring can be used to demonstrate that overlying contaminants have not migrated into the vadose zone and also that existing contaminants in the vadose zone are not moving

The most commonly used monitoring tool in the vadose zone is the suction lysimeter Suction lysimeters are installed in the vadose zone beneath the hazardous waste site and beneath any low permeability liners Backup lysimeters are often installed beneath or adjacent to the primary lysimeter to verify results

#### **A 2 3 3      Fugitive Dust Monitoring**

Monitoring of fugitive dust primarily includes radiological surveys These surveys can be used to demonstrate that contaminated soils are not migrating via the wind/air dispersion pathway Ambient air samplers monitor airborne dispersion of radioactive materials Samplers

operate continuously at a volumetric flow rate of approximately 12 liters per second collecting air particles on fiberglass filters

### **A 3 CONTAINMENT**

Containment interrupts the exposure pathways to contaminated soil and prevents or reduces migration of hazardous substances into the surrounding environment. While containment reduces the mobility of the contaminants, it does not reduce their toxicity or volume. Containment technologies include horizontal and vertical barriers.

#### **A 3 1 Vertical Barriers**

Vertical barriers prevent horizontal migration of contamination by introducing or creating a physical barrier around all or part of the contaminated soil mass. Slurry walls and synthetic membrane cutoff walls are types of vertical barriers.

##### **A 3 1 1 Slurry Wall**

These subsurface barriers consist of a vertically excavated trench filled with a slurry. The slurry, usually a mixture of bentonite and water, hydraulically shores the trench to prevent collapse and forms a filter cake to reduce groundwater flow. In some cases, soil or cement is added to the bentonite slurry to form a soil bentonite or cement bentonite barrier. Slurry walls can be keyed to a confining layer of clay or bedrock or left hanging when contaminants such as petroleum hydrocarbons do not mix with the groundwater. Slurry walls are often used where the waste mass is too large for practical treatment and where soluble and mobile constituents pose an imminent threat to a drinking water source. They are economical at moderate depths (40 to 70 feet) and have a low water permeability (from  $10^{-5}$  to  $10^{-8}$  cm/sec). Slurry walls have been successfully implemented at hazardous waste sites, are applicable to the full range of contaminants with no particular target group, but are considered capital intensive.

The following factors may limit the applicability and effectiveness of the process:

The technology only contains the contaminants to a specific area.

Soil bentonite backfills are not able to withstand attack by strong acids, bases, salt solutions, and some organic chemicals. There is some concern regarding the permeability of slurry walls to certain organic compounds.

There is the potential for the slurry walls to degrade or deteriorate over time, and

The trenches are generally limited to an excavated depth of approximately 30 feet using conventional backhoes. Greater depths, approaching 70 feet, can be achieved using telescopic backhoes or clamshells.

### **A 3 1 2      Synthetic Membrane Cutoff Wall**

Synthetic membranes are used to form a cutoff wall to divert or contain groundwater. Compatibility testing of the liners with chemical wastes must be performed to determine durability. To place a synthetic membrane liner as a vertical barrier, a trench must be dug from the surface to an impervious soil layer, and a drain must be placed in the bottom of the trench to remove excess water. The synthetic membrane must be suspended vertically in the trench, and the trench must be backfilled with sand or other suitable material. To be effective, the liner must be keyed into the underlying impervious barrier. During construction, the trench must remain open to facilitate placement of the liner. Extra precautions must be taken when working with loose, unconsolidated materials to ensure proper placement of the liner.

The following factors may limit the applicability and effectiveness of the process:

The technology only contains the contaminants to a specific area.

Construction, depending on site conditions, may be difficult, and the synthetic membrane may become damaged, and

The trenches are generally limited to an excavated depth of approximately 30 feet using conventional backhoes. Greater depths, approaching 70 feet, can be achieved using telescopic backhoes or clamshells.

### **A 3 2      Horizontal Barriers**

Horizontal barriers reduce contaminant migration from soils and sediments by minimizing contaminant entrainment as dust, leaching, infiltration, and/or contact with surface water runoff. Horizontal barriers are effective in containing organic and inorganic contaminated soils.

Exposure pathways to contaminants in soils and sediments are also interrupted by horizontal barriers. Horizontal barriers include caps and covers, grout injection, pavement, and sprayed sealants.

#### **A 3 2 1      Vegetative Cover**

Vegetative cover processes include grading and backfilling the contaminated area with general backfill/topsoil material, planting vegetation, and applying pea gravel.

The following factors may limit the applicability and effectiveness of the process

Backfilling and grading provide no hydraulic barriers to prevent infiltration of precipitation into underlying material

Soil types and availability of water are critical for development of a vegetative surface

Periodic repair and maintenance may be required

The process is not usually considered a long term containment process and

Monitoring and a leak detection system may be required

### **A 3 2 2      Asphalt Based Cover**

An asphalt based cover involves placing an asphalt layer over a crushed stone bedding layer directly on the site surface. Before the pavement is placed, the site surface must be compacted and graded to prevent differential settlement. Pavement is subject to cracking through weathering processes and has not frequently been used for long term containment of hazardous wastes.

The following factors may limit the applicability and effectiveness of the process

The technology only contains the contaminants in a specific area

Pavement is susceptible to damage by weather (e.g. sun and the freeze/thaw cycle) plants and animals

Design life may be inappropriate for the contaminants of concern

Periodic repair and maintenance may be required

The process is not usually considered a long term containment process and

Monitoring and a leak detection system may be required

### **A 3 2 3      Compacted Clay Cover**

Compacted clay is frequently used in single or multiple layers in the final cover system of both hazardous and municipal waste landfills. These cover systems may also be used to contain contaminated soils. Bentonite, a natural clay with high swelling properties, is often transported to a site and mixed with onsite soil to produce a low permeability cover material. Onsite soils can sometimes be compacted to achieve the required permeability of  $1 \times 10^{-7}$  cm/sec.

or less Vegetation is typically the final surface of a cover system Proper vegetation reduces the damaging effects from erosion due to wind and surface water runoff

The following factors may limit the applicability and effectiveness of the process

The technology only contains the contaminants in a specific area

The uniformity of compacted soil walls is difficult to control

The cover may require large volumes of construction material

Weathering (cracking) of the clay cover may require extensive maintenance and

Monitoring and a leak detection system may be required

#### **A 3 2 4 Multi Layer Cover**

Clay compacted soil or synthetic membranes are frequently used in single or multiple layers in the final cover system of both hazardous and municipal waste landfills These cover systems may also be used to contain contaminated soils Bentonite a natural clay with high swelling properties is often transported to a site and mixed with onsite soil to produce a low permeability cover material Onsite soils can be compacted to achieve the required permeability of  $1 \times 10^{-7}$  cm/sec or less The most common synthetic membrane materials are polyvinyl chloride polyethylene butyl rubber Hypalon® and neoprene

An example of a multi layer cover consists of the following (1) a gas-collection layer (2) a composite hydraulic barrier layer combining a compacted-clay and a flexible membrane liner (3) a biotic barrier and drainage layer (4) a topsoil layer and (5) a permanent vegetative cover

The following factors may limit the applicability and effectiveness of the process

The technology only contains the contaminants in a specific area

The uniformity of compacted soil walls is difficult to control

Synthetic membrane materials can be easily damaged by weather human activity and animals

Synthetic membrane materials can degrade over time and may need to be maintained or replaced and

Monitoring and a leak detection system may be required

*In situ* treatment of contaminated soils and sediments is conducted without removal of contaminated material. *In situ* treatment technologies are generally not as well developed or tested as direct treatment equivalents and are highly dependent on site conditions. *In situ* technologies may also involve the delivery of solutions or reagents to the zone of contamination as well as the control of the spread of contaminants and treatment reagents beyond the subsurface treatment zone. Applicability of *in situ* methods must generally be established on a site specific basis by pilot scale treatability studies. *In situ* treatments include biological, chemical/physical, and thermal treatments.

#### **A 4 1 Biological Treatment**

Bioremediation uses naturally occurring micro-organisms such as bacteria, fungi, or yeast to degrade harmful chemicals into less toxic or nontoxic compounds. Micro-organisms like all living organisms need nutrients (such as nitrogen, phosphate, and trace metals), carbon, and energy to survive. Micro-organisms break down a wide variety of organic (carbon containing) compounds found in nature to obtain energy for their growth. Many species of soil bacteria, for example, use petroleum hydrocarbons as a food and energy, transforming them into harmless substances consisting mainly of carbon dioxide, water, and fatty acids. Bioremediation harnesses this natural process by promoting the growth of micro-organisms that can degrade contaminants and convert them to less toxic or nontoxic byproducts. The major *in situ* biological treatment technologies include biodegradation, bioventing, bio-uptake, and land farming/agricultural practices.

#### **A 4 1 1 Enhanced Bioremediation**

The activity of naturally occurring microbes is stimulated by circulating water based solutions through contaminated soils to enhance *in situ* biological degradation of organic contaminants. Nutrients, oxygen, or other amendments may be used to enhance bioremediation and contaminant desorption from subsurface materials. Generally, the process includes above ground treatment and conditioning of the infiltration water with nutrients and an oxygen (or other electron acceptor) source. Bioremediation has been successfully applied at hazardous waste sites.

The following factors may limit the applicability and effectiveness of the process:

Extensive treatability studies and site characterization may be necessary.

The circulation of water based solutions through the soil may increase contaminant mobility and necessitate use of an aboveground system for treating water prior to re-injection or disposal.

The injection of micro-organisms into the subsurface is not recommended and naturally occurring organisms are generally adapted to the contaminants present

Preferential flow paths may severely decrease contact between injected fluids and contaminants throughout the contaminated zones

The system should be used only where groundwater is near the surface and where the groundwater underlying the contaminated soils is contaminated

The system should not be used for clay highly layered or heterogeneous subsurface environments due to oxygen (or other electron acceptor) transfer limitations and

Bioremediation may not be applicable at sites where there are high concentrations of heavy metals highly chlorinated organics or inorganic salts

Target contaminants for *in situ* bioremediation are non halogenated volatile and semivolatile organics and petroleum hydrocarbons Halogenated volatile and semivolatile organics and pesticides also can be treated but the process may be less effective and may only be applicable to some of these compounds

The overall cost of *in situ* bioremediation should be in the range of \$100-\$300/ton

*In situ* bioremediation is considered operations and maintenance (O&M) intensive Various quantities of nutrients or other amendments must be obtained and circulated through contaminated soils and their concentrations and effects on contaminant degradation rates must be monitored

*In situ* bioremediation has been demonstrated to treat low levels of organic contaminants and is especially attractive at sites where soil excavation is difficult or expensive or where soil remediation can be tied into groundwater treatment The most common type of *in situ* bioremediation treatment involves aerobic degradation of contaminants adsorbed onto soils within the saturated zone of a site The process involves the addition of small amounts of nutrients (ammonia and phosphate) and large quantities of an oxygen source (e g , hydrogen peroxide) This is accomplished by injecting nutrient-enriched solutions into the contaminated zone through a series of wells or trenches and recovering the downgradient groundwater

For the process to be effective the injection/recovery system must provide for the transport of nutrients throughout the entire contaminated zone If possible this should follow the contaminant pathway This is particularly difficult in the vadose zone or at sites with complex underlying geology or low permeability soils Methane-oxidizing processes may be effective in enhancing degradation of volatile halogenated compounds

Anaerobic bioremediation has not been demonstrated for *in situ* applications because of the difficulty in maintaining an oxygen free environment and because of the temperature sensitivity of the microbes. Research is currently being conducted to investigate the feasibility of anaerobic bioremediation for deep soils or aquifers.

#### **A 4 2            Chemical/Physical Treatments**

Physical treatment is a process in which the hazardous waste is separated from its carrier by various physical methods including adsorption, distillation, and filtration. Physical treatment is applicable to a wide variety of wastes, but further treatment is usually required. For this reason, physical treatment is often discussed along with chemical treatment.

Chemical treatment is a process in which the hazardous waste is altered by a chemical reaction to destroy the hazardous component. Wastes that can be treated by this method include both organic and inorganic compounds. Drawbacks to this method include the inhibition of the treatment process reaction by impurities in the waste and the potential generation of hazardous byproducts.

The major *in situ* physical/chemical technologies include pneumatic fracturing, soil flushing, hydrolysis, chemical oxidation, and soil vapor extraction.

##### **A 4 2 1          Pneumatic Fracturing**

Pneumatic fracturing is normally combined with other *in situ* processes such as soil flushing or vapor extraction to improve contaminant removal. Pressurized air is injected beneath the surface to develop cracks in low permeability and over-consolidated sediments. These new passageways increase the effectiveness of many *in situ* processes and enhance extraction efficiencies.

The following factors may limit the applicability and effectiveness of the process:

The technology should not be used in areas of high seismic activity.

Investigation of possible underground utilities, structures, or trapped free product is required, and

The potential exists to open new pathways for the unwanted migration of contaminants (e.g., dense non aqueous phase liquids).

Pneumatic fracturing is applicable to the complete range of contaminant groups with no particular target group. The technology is used primarily to fracture clays and bedrock, but has applications in aerating sandy formations. Normal operation employs a two-person crew who make 25 to 40 fractures per day with a fracture radius of 15 to 20 feet (4.6-6.1 meters) to a depth of 50-100 feet (15.2-30.5 meters).

The normal cost range for pneumatic fracturing is \$5 \$10/ton (\$5 50-\$11 00/metric ton)  
Pneumatic fracturing is not considered capital or O&M intensive

#### **A 4 2 2      Soil Gas Venting**

If organic hazardous or nonhazardous waste is deposited in a pit trench or landfill landfill gas (LFG) production can be expected Landfill gas is produced by anaerobic decomposition of organic material and consists primarily of methane and carbon dioxide but could also contain small concentrations of other volatile organic gases such as vinyl chloride LFG can be flammable and sometimes explosive Landfill gas can move vertically and laterally through soils under a pressure gradient or a concentration gradient via diffusion

Landfill gas from hazardous waste sites is currently either vented into the atmosphere or collected and flared or incinerated Atmospheric vent systems usually consist of a series of horizontal perforated collection pipes located on top of the landfilled material and under the final cover the LFG is vented to the atmosphere via vertical riser pipes Alternatively the LFG can be collected via an extraction blower and flared or incinerated if it is too toxic or odoriferous for direct ventilation

#### **A 4 2 3      Soil Vapor Extraction**

Soil vapor extraction (SVE) applies a vacuum through extraction wells to create a pressure gradient that induces volatile compounds to diffuse through the soil to extraction wells The basic components of an *in situ* vacuum extraction system include production wells monitoring wells and high vacuum pumps The vacuum pumps are connected via a piping system to a series of production wells drilled through the contaminated soil zone Spacing of the production wells is determined by mathematical models or pilot testing Monitoring wells are drilled around the production wells to monitor the interstitial air pressure Placing air injection wells between the production wells or placing an impermeable cover over the surface of the zone being treated may improve air flow through the soil These approaches prevent the air in the vicinity of the production wells from short-circuiting by constraining the air to flow laterally through the soil The process includes a system for handling off gases The system for handling the off gases usually includes a liquid/vapor separator and is treated by an activated carbon bed catalytic converter or afterburner This process also is known as *in situ* soil venting *in situ* volatilization enhanced volatilization and soil vacuum extraction

The following factors may limit the applicability and effectiveness of the process

High humic content of soil inhibits contaminant volatilization

Heterogeneous soil conditions may result in inconsistent removal rates and

Low soil permeability limits subsurface air flow rates and reduces process efficiency

Halogenated and non halogenated volatile organic compounds and petroleum hydrocarbons are the target contaminant groups for *in situ* SVE (Stinson 1989). The technology is applicable only to volatile compounds with a Henry's Law constant greater than 0.01 or a vapor pressure greater than 0.5 units. *In situ* SVE generally applies only to the vadose zone. Treatment of the saturated zone is only possible by artificially lowering the water table. Since SVE is an *in situ* remedy and all contaminants are under vacuum until treatment, the possibility of contaminant release is reduced.

Data indicate that the overall cost for *in situ* SVE is typically under \$50/ton, excluding treatment of off gases and collected groundwater. SVE is considered O&M intensive.

*In situ* SVE may be enhanced by the injection of heat using thermal technologies. Since higher temperatures cause enhanced volatilization and the configuration of the systems requires a thermal component, details of thermally enhanced SVE are presented in Section A 4.4.3 under Thermal Treatments.

#### **A 4.2.4 Electrokinetics**

Electrokinetic soil processing is an *in situ* continuous process for the removal of ionic or charged species from soils including heavy metals, radionuclides, and selected organic pollutants. Electrokinetics is the process of passing a low intensity direct current through contaminated soil. The double-layer theory plays an important role when electric potential is applied to the soils. For soil particles, the double layer consists of a fixed layer of negative ions that are firmly held to the solid phase and a diffuse layer of cations and anions that are more loosely held. Applying an electric potential to soil promotes migration of the loosely held ions to their respective electrodes, dragging water molecules along with them as they move toward the electrodes. The electric field is expected to increase the leaching rate of heavy metals, which can be precipitated from solution by establishing appropriate pH and osmotic gradients. To date, electrokinetics has not been demonstrated beyond the bench scale for remediation of contaminated soil. The energy requirements are quite high during implementation of the process.

#### **A 4.2.5 Electroacoustic Soil Decontamination**

*In situ* electroacoustic soil decontamination is an emerging technology used for decontamination of soils containing hazardous organics by applying electrical (direct current) and acoustic field. The direct current facilitates the transport of liquids through soils. The process consists of electrodes (an anode and a cathode) and an acoustic source. Applying an electric potential displaces ions loosely held on soil particles, and the cations drag water along with them as they move toward the cathode. Although the phenomenon is not fully understood, an acoustic field can enhance the dewatering or leaching of wastes such as sludges when properly applied in conjunction with an electric field and water flow. One other possible application of the acoustic field is unclogging recovery wells. The technology is most applicable for fine grained clay soils. Early results indicate that electroacoustic soil decontamination is technically feasible.

for removal of inorganic species such as zinc and cadmium from clay soils and only marginally effective for hydrocarbon removal (SITE Technology Profile undated)

#### **A 4 3        Solidification/Stabilization**

Contaminants are physically bound or enclosed within a stabilized mass (solidification) and/or chemical reactions are induced between the stabilizing agent and contaminants to reduce their mobility

The following factors may limit the applicability and effectiveness of the process

Depth of contaminants

Environmental conditions which affect the ability to maintain immobilization of contaminants

A significant increase in volume (up to double the original volume) with some processes and

Incompatibility of certain wastes with this process    treatability studies may be required

The target contaminant group for *in situ* solidification/stabilization is inorganics    The technology's effectiveness against halogenated and non halogenated semivolatile organic compounds and pesticides is currently limited however systems designed to be more effective in treating organics are being developed and tested    *In situ* solidification/stabilization is relatively simple uses readily available equipment and has high throughput rates compared to other technologies

Overall cost of *in situ* solidification/stabilization should be less than \$100/ton    *In situ* solidification/stabilization is considered to be capital intensive

*In situ* solidification/stabilization technologies include    pozzolanic based solidification    cement based solidification    and proprietary agent solidification

#### **A 4 3 1        Stabilization**

Stabilization refers to a process by which a waste is converted to a more chemically stable form    The term may include solidification and the use of a chemical reaction to transform the toxic component to a new nontoxic compound or substance    Biological processes however are not considered    Stabilization or solidification is often accomplished using proprietary agents to react with or bind wastes under *ex situ* conditions

Most proprietary processes are protected from unauthorized use by patent or copyright laws. Several proprietary agent processes are very similar and therefore extensive bench scale testing is advisable. Acceptable results from testing of more than one process can achieve cost savings through competitive pricing.

Stabilization uses a variety of chemical agents to react with soil contaminants to produce a less mobile or less toxic compound. A number of proprietary solidification agents have been used for *in situ* solidification/stabilization at hazardous waste sites. This process is similar to pozzolanic based solidification/stabilization using conventional earth moving equipment or modified drilling techniques for mixing. Several proprietary agent binders are available to assist in binding organics; however, the process works best for inorganics and metals. Some agents used in this process may cause a significant volume increase in treated soil.

#### **A 4 3 2      Slurry Injection**

Slurry injection includes the injection of a slurry mixture containing chemical reagents into the soil where it hardens and immobilizes any contaminants. Slurry injection is an innovative technology and its long term effectiveness is unknown.

The following factors may limit the applicability and effectiveness of the process:

- Contaminants immobilized but not removed

- Freeze/thaw degradation

- Rocks larger than 10 inches

- Soil volume increases of up to 8.5 percent and

- Access would be required for a drill rig and mixing equipment

#### **A 4 3 3      Solidification**

Soil mixing techniques and pozzolanic agents are used to produce a solidified soil mass. The required equipment and materials are readily available and the process is considered to be a proven, established, full scale technology.

The following factors may limit the applicability and effectiveness of the process:

- Reduces mobility and results in an increase in soil volume

- High organic concentrations may impede setting and binding

- Heterogeneous and high moisture soil may be more difficult to treat

Pilot testing may be needed to specify design requirements and

Maintenance of the solidified mass monitoring and periodic sampling may be required

#### **A 4 3 4      Cementation**

Cement based and pozzolanic based solidification/stabilization has been used for *in situ* applications at several hazardous waste sites. This technology requires a method to mix the solidification/stabilization cementitious agents with the soil in place. Conventional earth moving equipment can be used for mixing at shallow depths but greater depths require a more sophisticated mixing method such as that presented for slurry injection solidification.

#### **A 4 3 5      Encapsulation**

Encapsulation is a process involving the complete coating or enclosure of waste particles individually (microencapsulation) or as an agglomerated mass (macroencapsulation). The process is typically performed on excavated and/or already treated or drummed wastes. However, this process may be applied under *in situ* conditions using existing injection grouting technology or existing soil mixing technology for shallow soils. No reference to the successful use of the *in situ* process was found in the literature; however, it has been cited as having significant applicability and promise by Freeman (1989).

#### **A 4 3 6      Vitrification**

*In situ* vitrification is the process of decomposing organic contaminants and melting wastes, soils, or sludges in place to bind the waste into a glassy solid matrix that is very resistant to leaching. This is accomplished by electrically melting soil at temperatures between 2900 and 3600 degrees Fahrenheit. Organic vapors and airborne particulates from the organic contaminants and some inorganic contaminants are collected at the surface under a hood and drawn into an off gas treatment system. Electricity is typically supplied by a utility distribution system transmitting 12 500 or 13 800 volts. The resulting product is a monolithic mass with a microcrystalline structure similar to that of naturally occurring obsidian. Vitrification is currently in pilot scale development with some applications at hazardous waste sites.

The following factors may limit the applicability and effectiveness of the process:

The process requires homogeneity of the media.

*In situ* vitrification is only effective to a maximum depth of approximately 30 feet.

Organic and inorganic off gases must be controlled.

*In situ* vitrification is limited to operations in the vadose zone

Soil moisture may increase the process costs

Buried metals in excess of 5 percent of the melt weight or continuous metal that occupies 90 percent of the distance between two electrodes will hinder performance and

There may be insufficient silica in the treatment volume to form the desired residual material

While *in situ* vitrification is used primarily to encapsulate non volatile inorganic elements temperatures of approximately 3000 F (1600 C) destroy organic contaminants by pyrolysis *In situ* vitrification will result in a volume reduction of 20-40 percent depending on the material void volume A vacuum hood placed over the treated area collects off gases which are treated before release The entire process may be conducted in a vacuum greatly reducing the possibility of contaminant release Controlling the off gases and the high voltage used in the *in situ* vitrification process presents some health and safety risks

The cost of *in situ* vitrification has been estimated to be approximately \$790/ton (\$870/metric ton) *In situ* vitrification is a relatively complex technology requiring highly skilled and trained operators It is considered to be both capital and O&M intensive

#### A 4 4 Thermal Treatment

Thermal treatment involves the application of thermal energy to contaminated soils or hazardous waste by various means Thermal energy can be used to combust or burn contaminants volatilize contaminants or trap contaminants within a vitrified mass Depending on the application temperatures of the treated material can be raised slightly or dramatically When subjected to elevated temperatures organic wastes can decompose to less toxic forms or can volatilize and be captured Complete combustion yields carbon dioxide and water plus small amounts of carbon monoxide nitrous oxides and chlorine and bromine acid gases Some thermal processes produce off gases and ash that require further treatment or landfill disposal Thermal treatment is most suitable for organic wastes and is less effective when attempting to detoxify heavy metals and inorganic compounds Thermal treatments may be applied to enhance chemical/physical treatments such as SVE One drawback of thermal treatment is the high cost involved

### **A 4 4 3      Thermally Enhanced Soil Vapor Extraction**

Thermally enhanced SVE uses steam/hot air injection or electric/radio frequency heating to increase the mobility of volatiles to facilitate extraction. The process includes a system for handling off gases. Thermally enhanced SVE has been applied to contaminated soils at hazardous waste sites and is designed to treat halogenated and non halogenated semivolatile organic compounds. Thermally enhanced SVE technologies are also effective in treating some pesticides depending on the temperatures achieved by the system. The technology may also be used to treat some halogenated and non halogenated volatile organic compounds and petroleum hydrocarbons but effectiveness may be limited.

The following factors may limit the applicability and effectiveness of the process

Debris or other large objects buried in the media can cause operating difficulties

Use of the technology is limited to a slope of 5° or less

Performance varies depending upon the process selected because of the maximum temperature achieved and

The soil structure at the site may be modified depending upon the process selected

The thermally enhanced SVE processes used by each vendor are notably different and should be investigated individually for more detailed information. Heating mechanisms employed by vendors may include but are not limited to radio frequency heating (Section A 4 4 2) and 6-phase heating. A 6-phase heating demonstration project is underway at RFETS. Results will be available under separate cover. Since thermally enhanced SVE is an *in situ* remedy and all contaminants are under a vacuum during operation, the possibility of contaminant release is minimal.

Available data indicate that the overall cost for treatment using thermally enhanced SVE systems is approximately \$50-\$75/ton (\$55-\$82/metric ton) excluding treatment of off gases and groundwater. Thermally enhanced SVE is considered to be both capital and O&M intensive.

### **A 5              REMOVAL**

Contaminated material may be removed and transported to treatment and/or disposal facilities. Excavation is one type of removal technology and is applicable to all the contaminants. Removal actions are performed on contaminated soils so they can be treated aboveground or disposed of. Long term exposure pathways associated with the contaminated soils are therefore minimized or eliminated. Excavation may create short term risks associated with fugitive dust, direct exposure to contaminated soils, and physical hazards related to excavation equipment.

The following factors may limit the applicability and effectiveness of the removal technologies

Generation of fugitive emissions may be a problem during removal operations

The distance between the contaminated site and the nearest treatment/disposal facility may be too great

Community acceptability may be difficult

Depth and composition of the media requiring excavation must be considered

Applicable Land Disposal Restrictions must be considered

Quantity of contaminated soil may be impractical

Characteristics of contaminated soil may be limiting and

Site-specific conditions (i.e. topography location geology) may be limiting

#### **A 5 1      Excavation**

Excavation includes all excavation techniques used in removing wastes or contaminated material. Conventional techniques and equipment are used for most hazardous waste remediation with modifications to procedures or equipment to ensure the health and safety of equipment operators, the public, and the environment. When removal of wastes requires drastic modification to conventional equipment or procedures, techniques are used. These processes include robotic technologies, excavation within emission control enclosures, excavation using foam suppressants, and other techniques to handle special situations posed by highly toxic, corrosive, explosive, or sensitive wastes.

The following factors may limit the applicability and effectiveness of the process

Groundwater table elevation may cause problems with excavation

The costs associated with excavating sites containing radioactive, reactive, or highly toxic waste material may be prohibitive

The generation of fugitive emissions may be a problem during operations

Requirements for sensing/monitoring equipment at the dig face may be problematic

The potential exists to open new pathways for the unwanted migration of contaminants and

Excavation may become cost prohibitive at great depths or in complex hydrogeologic conditions

## **A 5 2        Short Distance Transport**

Transportation is the physical removal of soil from a site after excavation. Transport actions do not treat contaminants but provide a means of moving contaminated materials to onsite or offsite treatment facilities. Short distance transport includes processes that move contaminated material relatively short distances. For example, short distance transport may include transport of contaminated material from the site of removal to a treatment facility located onsite or from a staging or stockpiling area to a treatment facility. Short distance transport methods include conveyor systems, slurry pipelines, and truck hauling methods. Soils may be placed in drums or rolloff containers prior to transportation. The selection of a specific transport process must consider the distance and purpose of transport.

### **A 5 2 1        Conveyor System**

Conveyor systems can be used to transport contaminated materials as part of a treatment alternative or processing system. They require removal, loading system, and potentially additional transport methods to move contaminated materials from one location to another. Conveyor systems are readily available under numerous designs to meet various process design requirements. Conveyor systems are typically used to transport materials over relatively short distances as temporary or long term systems.

The following factors may limit the applicability and effectiveness of the process:

The distance between the contaminated site and the nearest treatment/disposal facility

Quantity of the contaminated material

Characteristics of the contaminated material and the material compatibility with the transport system

Site access and topography and

Control and monitoring of fugitive emissions during transport

## **A 5 2 2      Slurry Pipeline**

A slurry pipeline consists of a pipeline and pump equipment used to transport soil materials in slurry form. A slurry pipeline requires removal of soils equipment to generate a slurry from the soil piping and pumps to move the slurry to a treatment facility. Slurry pipeline systems are relatively short (because of costs involved) and are used as a component of treatment systems e.g. soil washing. A slurry pipeline may be used as a temporary or long term transport system.

The following factors may limit the applicability and effectiveness of the process

The distance between the contaminated site and the nearest treatment/disposal facility

Quantity of the contaminated material

Characteristics of the contaminated material and its compatibility with the transport system

Site access and topography

Control and monitoring of fugitive emissions during removal and slurry generation and

Possible problematic separation and treatment of water from the slurry

## **A 5 2 3      Truck Hauling**

Contaminated materials can be transported to onsite treatment facilities by various sizes of trucking vehicles and earthmoving equipment. Truck transport may require containerization of contaminated material during transport. A loading process as well as monitoring or control of fugitive emissions may also be required during transport.

The following factors may limit the applicability and effectiveness of the process

The distance between the contaminated site and the nearest treatment/disposal facility

Quantity of the contaminated material

Characteristics of the contaminated material and its compatibility with the transport system

Site access and topography and

Control and monitoring of fugitive emissions during removal and slurry generation

### **A 5 3 Long Distance Transport**

Transportation is the physical removal of soil from a site after excavation. Transport actions do not treat contaminants but provide a means of moving contaminated materials to onsite or offsite treatment facilities. Long distance transport includes processes that move contaminated material across long distances. For example, long distance transport may include transport of contaminated material from the site of removal to treatment or disposal facility. Soils may be placed in drums or rolloff containers prior to transportation. The selection of a specific transport process must consider the distance and purpose of transport. Long distance transport includes primarily truck and/or rail transport.

#### **A 5 3 1 Truck/Rail Hauling**

Contaminated materials can be transported by truck or rail systems. Various sizes of trucking vehicles and earthmoving equipment may be used to transport contaminated materials to onsite or offsite treatment facilities. In place or constructed rail systems may also be used. Truck or rail transport may require containerization of contaminated material during transport. A loading process as well as monitoring or control of fugitive emissions may also be required during transport.

The following factors may limit the applicability and effectiveness of the process:

The distance between the contaminated site and the nearest treatment/disposal facility

Quantity of the contaminated material

Characteristics of the contaminated material and its compatibility with the transport system

Site access and topography

Control and monitoring of fugitive emissions during removal and slurry generation

Applicable U S Department of Transportation (DOT) regulations and

Community acceptance

## **A 5 4        Offsite Storage/Disposal**

Storage of hazardous waste is not a true treatment that reduces toxicity volume or mobility of a waste. However, storage occurs prior to treatment and after removal of a waste. Disposal is a broad term to describe treatment of a waste. Landfilling has been the most commonly practiced method of disposing of municipal, industrial, and hazardous wastes. The primary advantage of landfilling is its simplicity compared to other technologies and the ability of landfills to handle large volumes of waste. A hazardous waste landfill contains and isolates hazardous wastes that are not currently recoverable to ensure present and long term environmental protection. To accomplish these objectives, the landfill must be planned, designed, constructed, operated, and maintained in accordance with federal, state, and local regulations (Freeman, 1988).

Offsite permanent disposal options include the use of a landfill or other treatment, storage, and disposal (TSD) facility. Offsite storage and disposal require transport of potentially radioactive wastes over public roads or railroads. A permitted commercial TSD facility must also accept responsibility for the waste.

### **A 5 4 1        Landfill/TSD Facility**

Disposal of hazardous materials at a commercial TSD landfill facility is becoming increasingly difficult because of restrictions on landfilling certain chemicals, restrictions on transportation of hazardous wastes (particularly across state lines), and the high costs charged by commercial disposal facilities to accept wastes.

The following factors may limit the applicability and effectiveness of the process:

The distance between the contaminated site and the nearest disposal facility

Compliance with all federal, state, and local regulations, including but not necessarily limited to DOT and RCRA regulations

Quantity of the contaminated material

Characteristics of the contaminated material, and

Community acceptability

## **A 5 5        Onsite Storage/Disposal**

Storage of hazardous waste is not a true treatment that reduces toxicity, volume, or mobility of a waste. However, storage occurs prior to treatment and after removal of a waste. Disposal is a broad term to describe treatment of a waste. Landfills have been the most commonly practiced method of disposing of municipal, industrial, and hazardous wastes. The primary advantage of landfilling is its simplicity compared to other technologies and the ability

of landfills to handle large volumes of waste. A hazardous waste landfill contains and isolates hazardous wastes that are not currently recoverable to ensure present and long term environmental protection. To accomplish these objectives the landfill must be planned, designed, constructed, operated, and maintained in accordance with federal, state, and local regulations (Freeman 1988).

Onsite disposal may be long term or short term and is dependent on storage and disposal permit requirements. Disposal vaults and container storage may be the most practical onsite storage processes. Container storage is not a permanent treatment but may be used to stage wastes for onsite treatment or prior to transport after removal. A disposal vault may also be a viable storage option depending on characteristics of the waste.

#### **A 5 5 1      Disposal Vault**

Disposal vaults are designed as retrievable, monitored containment structures for temporary storage of hazardous or mixed wastes. Disposal vaults can be aboveground or underground using aboveground landfill design technology or underground entombment structures. Concrete vaults with covers may be considered for underground entombment structures. Waste can be retrieved more easily when recovery, destruction, or detoxification proves to be technically or economically feasible.

#### **A 5 5 2      Container Storage**

Hazardous materials can be held in drums or specifically designed containers until cost effective treatment or disposal is carried out. Drums are cylindrical shipping containers for solids and liquids; they have a storage capacity of 12 to 110 gallons. A drum for storage of hazardous waste material must achieve minimum DOT standards. Drums can be metal, fiberboard, or plastic depending upon compatibility and structural requirements. Containers can also include structural holders of material (e.g., roll-off containers and dumpsters).

#### **A 5 5 3      Permitted Landfill**

The time associated with construction and operation of an onsite landfill is much shorter than for many treatment options. Landfills are classified based on their cover and liner systems and the types of wastes that may be disposed of in them. Depending on the concentrations and leachability of contaminants, contaminated soil and sediments could be placed in either an onsite hazardous waste landfill that is constructed according to the RCRA technology requirements or in an onsite industrial/municipal type landfill.

A typical hazardous waste landfill is constructed with a lower liner system consisting of at least one synthetic and one low permeability clay liner and a leachate collection and leak detection system. A network of monitoring wells is also placed around the perimeter of the landfill. The cover system consists of one or two synthetic or clay liners, a gas-collection

system and an infiltration-drainage system. In some instances a leak-detection system is also included in the cover system.

Industrial landfills are designed and operated similarly to RCRA hazardous waste landfills; however, industrial landfills accept only non-RCRA hazardous wastes. Liquids, reactive wastes, and other highly toxic wastes are also banned from industrial landfills. Municipal landfills are more simply constructed and therefore are suitable to receive only nonhazardous wastes. These landfills generally receive all wastes associated with municipalities, specifically excluding hazardous, agricultural, and mining wastes.

The following factors may limit the applicability and effectiveness of the process:

Quantity of the contaminated material

Characteristics of the contaminated material

Compliance with all federal, state, and local regulations, including but not necessarily limited to DOT and RCRA regulations

Site hydrogeologic, geologic, and weather conditions affecting the location, design, construction, operation, and maintenance of the landfill, and

Community acceptability

## **A 6            *EX SITU* TREATMENT**

*Ex situ* treatment requires excavation or removal of the contaminated soil or sediment prior to treatment. Direct treatment technologies include a wide range of processes that can reduce the toxicity, mobility, or volume of inorganic and organic contaminants in soil. The direct treatment technologies are discussed and grouped by biological, physical/chemical, and thermal processes.

### **A 6.1        Chemical/Physical Treatment**

Physical treatment is a process in which the hazardous constituent is separated from its carrier by various physical methods such as adsorption, distillation, and filtration. Physical treatment is applicable to a wide variety of wastes, but further treatment is usually required. For this reason, physical treatment is often discussed along with chemical treatment.

Chemical treatment is a process in which the hazardous constituent is altered by a chemical reaction that reduces or eliminates the toxicity of the contaminant. Wastes that can be treated by this method include both organic and inorganic compounds. Drawbacks to this method are that impurities in the waste may inhibit the treatment process, reaction, and hazardous

byproducts may be generated. The major direct physical/chemical treatment technologies include dehalogenation, reduction/oxidation, soil vapor extraction, soil washing, and solvent extraction.

#### **A 6 1 1      Chemical Reduction/Oxidation (Red/Ox)**

Reduction/oxidation chemically converts hazardous contaminants to non hazardous or less toxic compounds that are more stable, less mobile, and/or inert. The reducing/oxidizing agents most commonly used for treatment of hazardous contaminants are ozone, hydrogen peroxide, hypochlorites, chlorine, and chlorine dioxide. These reagents may be used in combination or with ultraviolet light to improve reduction/oxidation effectiveness. Chemical reduction/oxidation has been applied at both industrial and hazardous waste sites.

The following factors may limit the applicability and effectiveness of the process:

Incomplete oxidation or formation of intermediate contaminants may occur depending upon the contaminants and oxidizing agents used.

The process may not be cost-effective for high contaminant concentrations due to the large amounts of oxidizing agent required, and

Oil and grease in the media should be minimized to optimize process efficiency.

The target contaminant group for chemical reduction/oxidation is inorganics. The technology can be used but may be less effective against non halogenated volatile and semivolatile organic compounds, petroleum hydrocarbons, and pesticides. Excavation associated with chemical reduction/oxidation poses a potential health and safety risk to site workers through skin contact and air emissions. Personal protective equipment, at a level commensurate with the contaminants involved, is normally required during excavation operations.

The overall cost for this technology should be in the range of \$100-\$300/ton. Chemical reduction/oxidation is not considered to be either capital or O&M intensive.

#### **A 6 1 2      Soil Washing**

Contaminants sorbed onto soil particles are separated from soil in an aqueous based system. This often requires preliminary application of a physical separation process prior to soil washing. Organics amenable to water washing can be identified according to their soil/water partition coefficient, or estimated using their octanol/water partition coefficient. The wash water may be combined with a basic leaching agent, surfactant, acid or base for pH adjustment, or chelating agent to help remove organics or heavy metals. The solution is treated to remove the contaminants after the soil particles have been removed by precipitation or dewatering. Recovery and reuse of the reagents used in this process may be difficult. Soil washing has been successfully implemented to treat soils from both industrial and hazardous waste sites.

The following factors may limit the applicability and effectiveness of the process

Fine soil particles (silts clays) are difficult to remove from washing solutions

Complex waste mixtures (e g metals with organics) make formulating washing solutions difficult and

High humic content in soil inhibits desorption

The target contaminant groups for soil washing are halogenated and non halogenated semivolatile organic compounds petroleum hydrocarbons and inorganics The technology can be used on all contaminant groups but may be less effective on halogenated and non halogenated volatile organic compounds and pesticides The technology offers the potential for recovery of metals and can clean a wide range of organic and inorganic contaminants from coarse grained soils Excavation associated with soil washing poses a potential health and safety risk to site workers through skin contact and air emissions Personal protective equipment at a level commensurate with the contaminants involved is normally required during excavation operations

Average cost for use of this technology including excavation is approximately \$120-\$200 per ton (\$132 \$220/metric ton) and is dependent on the type of contamination and concentrations Soil washing is considered to be both capital and O&M intensive

#### **A 6 1 3 Solvent Extraction**

Waste and solvent are mixed in an extractor dissolving the organic contaminants into the solvent The extracted organics and solvent are then placed in a separator where the contaminants and solvent are separated for treatment and further use (McCoy 1989) The process can be operated continuously Solvent extraction has been applied at both industrial and hazardous waste sites and is being tested at RFETS to determine its effectiveness in removing radionuclides

The following factors may limit the applicability and effectiveness of the process

Organically bound metals can be extracted along with target organic pollutants

The presence of detergents and emulsifiers can influence the extraction performance

Traces of solvent may remain in the treated solids

The toxicity of the solvent is an important consideration

Solvent extraction is generally least effective on very high molecular weight organic and very hydrophilic substances and

Some soil types and moisture content levels will adversely impact process performance

The target contaminant groups for solvent extraction are halogenated and non halogenated semivolatile organic compounds and pesticides. The technology can be used to treat halogenated and non halogenated volatile organic compounds and petroleum hydrocarbons but it may not be as effective or applicable to all of these compounds. Excavation associated with solvent extraction poses a potential health and safety risk to site workers through skin contact and air emissions. Personal protective equipment at a level commensurate with the contaminants involved is normally required during excavation operations.

The overall cost for this technology is expected to be greater than \$300/ton. Solvent extraction is considered to be both capital and O&M intensive.

#### **A 6 1 4      Electrokinetics**

Electrokinetics is used to decontaminate soils by applying an electric field to facilitate the transport of liquids through soils. See Section A 4 2 4. The process is applied to *in situ* soil however the process can also be applied to an excavated or stockpiled quantity of soil.

#### **A 6 1 5      Physical Separation**

Physical separation of a contaminated soil is the process of separation by which components of the soil are removed from each other using gravity, circular acceleration, filters or sieves, and vibration without the application of chemicals or treatment of the contaminated soils.

#### **A 6 1 6      Magnetic Separation**

Magnetic separation uses the magnetic properties of metal contaminants to remove them from contaminated soils. High gradient magnetic separation relies on a strongly magnetic seeding agent such as magnetite to capture paramagnetic materials such as oxides of iron, manganese, copper, chromium, cobalt, and nickel. In the process, precipitation products, suspended solids, and the magnetite form a coagulum that is later removed.

#### **A 6 1 7      Dehalogenation**

Dehalogenation is the treatment process to remove unwanted halogens (e.g., F, Cl, Br, I) from compounds to make them less toxic or to facilitate further treatment. Two major examples of dehalogenation include base-catalyzed decomposition and glycolate

**A 6 1 7 1 Base-Catalyzed Decomposition** Base-catalyzed decomposition (BCD) is a dehalogenation/dechlorination process that strips off chloride in the PCB molecule and forms sodium chloride and biphenyls. Contaminated soil is screened, processed with a crusher and pug mill, and mixed with sodium bicarbonate. The mixture is heated to 630 F (333 C) in a rotary reactor to decompose and partially volatilize the contaminants. Dehalogenation (BCD) is a full scale technology but has had very limited use.

The following factors may limit the applicability and effectiveness of the process:

If the influent matrix includes heavy metals and certain non halogenated volatiles they will not be destroyed by the process, and

High clay and moisture content will increase treatment costs.

Halogenated semivolatile organic compounds and pesticides are the target contaminant groups for dehalogenation (BCD). The technology can be used to treat halogenated volatile organic compounds but may be less effective and applicable to only some compounds within this group. The dehalogenation (BCD) process was developed by EPA's Risk Reduction Engineering Laboratory (RREL) in cooperation with the Naval Civil Engineering Laboratory (NCEL) as a clean, inexpensive way to remediate soils and sediments contaminated with chlorinated organic compounds, especially PCBs. The excavation associated with BCD poses a potential health and safety risk to site workers through skin contact and air emissions. Personal protective equipment at a level commensurate with the contaminants involved is normally required during excavation operations.

Cost of this process is estimated at \$256 per ton. Inadequate information exists as to whether this technology is capital or O&M intensive.

**A 6 1 7 2 Glycolate** An alkaline polyethylene glycolate (APEG) reagent is used to dehalogenate halogenated aromatic compounds in a batch reactor. Potassium polyethylene glycolate (KPEG) is the most common APEG reagent. Contaminated soils and the reagent are mixed and heated in a treatment vessel. In the APEG process, the reaction causes the polyethylene glycol to replace halogen molecules and render the compound non hazardous. For example, the reaction between chlorinated organics and KPEG causes replacement of a chlorine molecule and results in a reduction in toxicity. Dehalogenation (glycolate) is a full scale technology.

The following factors may limit the applicability and effectiveness of the process:

The technology is generally not cost-effective for large waste volumes. Media water content above 20 percent requires excessive reagent volume.

Concentrations of chlorinated organics greater than 5 percent require large volumes of reagent, and

The resultant soil has poor physical characteristics

Halogenated semivolatile organic compounds and pesticides are the target contaminant groups for glycolate dehalogenation. The technology can be used but may be less effective against selected halogenated volatile organic compounds. APEG dehalogenation is one of the few processes available that has been successfully field tested in treating PCBs. The technology is amenable to small scale applications. Excavation associated with dehalogenation (APEG/KPEG) poses a potential health and safety risk to site workers through skin contact and air emissions. Personal protective equipment at a level commensurate with the contaminants involved is normally required during excavation operations.

The overall costs for the process are greater than \$300/ton. Dehalogenation (glycolate) is considered to be both capital and O&M intensive.

#### **A 6 1 8      Soil Vapor Extraction**

Soil vapor extraction (SVE) applies a vacuum to a network of aboveground piping placed in the excavated media to encourage volatilization of organics. The process includes a system for handling off gases. The process is very similar to *in situ* SVE and may be enhanced by the addition of thermal energy. Soil vapor extraction has been successfully applied to soils containing hazardous compounds.

The following factors may limit the applicability and effectiveness of the process

High humic content of soil inhibits volatilization and

The technology is incompatible with certain soil types

The target contaminant groups for SVE are halogenated and non halogenated volatile organic compounds. An advantage of the technology over its *in situ* counterpart is the increased number of passageways formed via the excavation process. Excavation associated with SVE poses a potential health and safety risk to site workers through skin contact and air emissions. Personal protective equipment at a level commensurate with the contaminants involved is normally required during excavation operations.

The overall cost for SVE is under \$100/ton (\$110/metric ton) including the cost of excavation but excluding treatment of off gases. SVE is not considered to be either capital or O&M intensive.

#### **A 6 2      Biological**

Biological treatment processes use naturally occurring micro-organisms such as bacteria, fungi, or yeast to degrade harmful chemicals into less toxic or nontoxic compounds. Micro-organisms like all living organisms need nutrients (such as nitrogen, phosphate, and trace

metals) carbon and energy to survive Micro-organisms break down a wide variety of organic (carbon-containing) compounds found in nature to obtain energy for their growth Biological processes can use natural process to promote the growth of micro-organisms that can degrade contaminants and convert them to less toxic or nontoxic byproducts

#### **A 6 2 1      Biological Leaching**

Biological leaching is a process intended to solubilize plutonium from soils Soils have been subjected to bench scale treatability studies The process uses thiobacillus amendments to assist with plutonium solubilization Available data have indicated removal of americium and plutonium from soils of up to 88 percent Test results indicate that since the soils were not sterilized native microbes may have competed with the proprietary microbes and a greater percentage of radionuclide removal may be possible

#### **A 6 3      Solidification/Stabilization**

Solidification/stabilization has been implemented at industrial and hazardous waste sites Contaminants are physically bound or enclosed within a stabilized mass (solidification) and/or chemical reactions are induced between the stabilizing agent and contaminants to reduce their mobility

The following factors may limit the applicability and effectiveness of the process

Environmental conditions may affect the long term immobilization of contaminants

Some processes can result in up to double the original volume

Certain wastes are incompatible with solidification/stabilization processes and

Treatability studies may be required

The target contaminant group for solidification/stabilization is inorganics The technology has limited effectiveness against halogenated and non-halogenated semivolatile organic compounds and pesticides However processes designed to be more effective against organic contaminants are being developed and tested Solidification/stabilization is relatively simple uses readily available equipment and has high throughput rates compared to other technologies Excavation associated with solidification/stabilization poses a potential health and safety risk to site workers through skin contact and air emissions Personal protective equipment at a level commensurate with the contaminants involved is normally required during excavation operations

Data from more than a dozen vendors indicate an approximate cost of under \$100/ton (\$110/metric ton) including excavation Solidification/stabilization is considered capital

intensive Solidification/stabilization technologies include pozzolanic based agent solidification cement based solidification and proprietary agent based solidification

### **A 6 3 1      Stabilization**

Stabilization refers to a process by which a waste is converted to a more chemically stable form. The term may include solidification and the use of a chemical reaction to transform the toxic component to a new nontoxic compound. Biological processes, however, are not considered. Stabilization or solidification is often accomplished using proprietary agents to react with or bind wastes under *ex situ* conditions.

Most proprietary processes are protected from unauthorized use by patent or copyright laws. Several proprietary agent processes are very similar and therefore extensive bench scale testing is advisable. Acceptable results from testing of more than one process can achieve cost savings through competitive pricing.

### **A 6 3 2      Encapsulation**

Encapsulation is a process involving the complete coating or enclosure of waste particles individually (microencapsulation) or as an agglomerated mass (macroencapsulation). The process is typically performed on excavated and/or already treated or drummed wastes. Organic binders include organic substances such as epoxys, polyesters, asphalt, polyethylene, and urea formaldehyde. Organic binders have been used in conjunction with inorganic binders used in cementitious stabilization. The encapsulation process is performed similarly to the cementitious stabilization process.

This process is applicable to all types of toxic contaminants including radionuclides depending on the binder's compatibility with the waste. Worked performed at RFETS (Faucette et al 1992) (Faucette 1993) demonstrate that polyethylene-encapsulated radioactive waste form will remain chemically and mechanically stable under any conceivable transportation and storage environment. In addition, macroencapsulation is the RCRA Method of Treatment for radioactive lead metal. Overmixing or undermixing has been identified as a potential problem and treatability studies are required to ensure the material's compatibility.

### **A 6 3 3      Cementation**

Cement based solidification is a specialized form of pozzolanic solidification/stabilization. The type of cement used for solidification/stabilization can be selected to emphasize a particular cementing reaction (EPA 1986). Pozzolans are frequently added to cement to react with any free calcium hydroxide and thus improve the strength and chemical resistance of the final product. Although much of the pozzolan in waste processing may be inactivated by the waste, any reaction that does occur between the cement and free silica from the pozzolan adds to the product strength and durability.

Cement/fly ash processes typically require the use of sorbents or other additives to stabilize and therefore decrease the loss of specific hazardous materials from the porous solid products. Such adaptations of the technology are also often necessary because some materials inhibit the binding action in cement. This process is used extensively for contaminated soil treatment.

Pozzolan based solidification utilizes materials that set into a solid mass when mixed with hydrated lime. Pozzolan materials include hydrated silicic acid, diatomaceous earth, blast furnace slag, ground brick, and some fly ashes. Solidification/stabilization of wastes using lime and pozzolan materials requires mixing the wastes to a pasty consistency with a carefully selected pozzolan. Hydrated lime (calcium hydroxide) is then blended into the waste pozzolan mixture. The resulting moist material is packed into a mold to cure, is backfilled, or is placed in a landfill and compacted.

Impurities such as organics, silt, and soluble salts may delay curing and setup of the matrix and may reduce strength and durability. In addition, additives increase the weight and bulk of the matrix. The technology and management of cement mixing and handling are well known, as is the chemistry of lime reactions. However, bench and pilot scale testing are usually warranted. Pozzolan based solidification is widely used for treatment of contaminated soils.

#### **A 6 3 4      Vitrification**

Contaminated soils and sludges are melted at high temperature to form a glass and crystalline structure with very low leaching characteristics. Non volatile inorganic elements are encapsulated in a vitreous slag while organic contaminants are destroyed by pyrolysis.

The following factors may limit the applicability and effectiveness of the process:

Organic and inorganic off gases need to be controlled.

Use or disposal of the resultant vitrified slag is required, and

Accessibility to a sufficient power supply is needed.

Vitrification is applicable to the full range of contaminant groups, but inorganics are the target contaminant group. Metals are encapsulated in the vitrified mass, resisting leaching for geologic time periods. Excavation associated with vitrification poses a potential health and safety risk to site workers through skin contact and air emissions. Personal protective equipment, at a level commensurate with the contaminants involved, is normally required during excavation operations. The high energy required for the vitrification process may constitute a health and safety concern.

Approximate overall cost is \$700/ton (\$770/metric ton) Vitrification is a relatively complex technology that requires excessive energy and trained personnel Vitrification is considered to be both capital and O&M intensive

#### **A 6 4 Thermal Treatments**

This treatment process involves decomposition of hazardous compounds by thermal means into less hazardous or non hazardous components Thermal energy can be used to combust or burn contaminants or volatilize contaminants When subjected to high temperatures organic compounds decompose to similar less toxic forms Complete combustion yields carbon dioxide and water plus small amounts of carbon monoxide nitrous oxides and chlorine and bromine acid gases Some thermal processes produce off gases and ash that require further treatment or landfill disposal Thermal treatment is most suitable for organic wastes and is less effective when attempting to detoxify heavy metals and inorganic compounds One drawback of thermal treatment is the high cost involved The major types of direct thermal treatment technologies include incineration desorption thermal distillation and pyrolysis

##### **A 6 4 1 Incineration**

High temperatures 1600 2200 F (871 1204 C) are used to volatilize and combust (in the presence of oxygen) organic constituents in hazardous wastes Seven common incinerator designs are fluidized bed infrared rotary hearth rotary kiln slagging fixed hearth and circulating bed The destruction and removal efficiency (DRE) for properly operated incinerators often exceeds the 99 99 percent requirement for hazardous waste and can be operated to meet the 99 9999 percent requirement for PCBs and dioxins All seven incinerator types have been implemented successfully to treat both industrial and hazardous wastes

The following factors may limit the applicability and effectiveness of the process

There are specific feed size and materials handling requirements that can impact applicability or cost at specific sites

The presence of volatile metals and salts may affect performance or incinerator life

Volatile metals including lead and arsenic leave the combustion unit with the flue gases or in bottom ash and may have to be removed prior to incineration

Metals can react with other elements in the feed stream such as chlorine or sulfur forming more volatile and toxic compounds than the original species and

Sodium and potassium can attack the brick lining and form a sticky particulate that fouls heat transfer surfaces

The target contaminant groups for incineration are all halogenated and non halogenated semivolatile organic compounds and pesticides. The technology also may be used to treat halogenated and non halogenated volatile organics and fuels but may be less effective. Excavation associated with incineration poses a potential health and safety risk to site workers through skin contact and air emissions. Personal protective equipment at a level commensurate with the contaminants involved is normally required during excavation operations. If an offsite incinerator is used, the potential risk of transporting the hazardous waste through the community must be considered.

Incineration costs are highly dependent upon the size of the contaminated site and the type of incinerator technology used. The cost to incinerate approximately 20 000 tons (18 200 metric tons) of contaminated media would be greater than \$300/ton (\$330/metric ton).

The capital expenditure associated with incinerators is relatively high. Materials handling, control of bed temperatures and residence times, and system maintenance make the technology O&M intensive as well.

**A 6 4 1 1 Fluidized Bed** The fluidized bed incinerator consists of a refractory lined vessel containing a bed of inert granular sand like material. Solids, sludges, and liquids can be injected directly into the bed or at its surface. If contaminated solid is being processed, the soil mass acts as the bed material and it must be crushed to a size less than 1 inch in diameter. In operation, combustion air is forced upward through the bed, which fluidizes the material at a minimum critical velocity. The heating value of the wastes, plus added fuel, maintains the desired combustion temperature in the vessel. The heat of combustion is transferred back into the bed, and the agitated mixture of waste, fuel, and hot bed material in the presence of fluidizing air provides a turbulent combustion environment.

The use of a large volume of heated bed material resists short term fluctuations in temperature and retention time due to changes in moisture, ash, or British Thermal Unit (BTU) content of the waste. Fluidized bed incinerators can be operated at lower temperatures than other incinerators because of the high mixing energies aiding the combustion process. This mixing offers the highest thermal efficiency while minimizing auxiliary fuel requirements and volatile metal emissions. The maximum operating temperature is limited by the fusion temperature of the sand fluidizing materials.

**A 6 4 1 2 Infrared Furnace** Infrared thermal units use silicon carbide elements to generate thermal radiation beyond the red end of the visible spectrum. Materials to be treated pass through the combustion chamber on a belt and are exposed to the radiant heat. Waste material should be less than 2 inches in diameter for optimal efficiency. In the combustion chamber, wastes can be either incinerated or pyrolyzed at 1400°F or 800 °C. Off gases flow to a gas fired secondary combustion chamber that provides complete destruction. Flue gas treatment is accomplished by any conventional off gas cleanup system.

Soils contaminated with PCBs dioxin and a variety of other wastes have been treated at pilot or full scale facilities using infrared electric furnaces. The current availability of this technology is uncertain.

**A 6 4 1 3 Molten Salt Incineration** A molten salt incinerator consists of a metal containment vessel containing sodium carbonate salts. The exterior of the containment vessel is heated with a gas burner or other suitable heat source to establish a molten salt bath at 1600 to 1800 F. Liquid or solid waste along with combustion air are injected into the salt bath through a downcomer. The air waste and combustion products bubble through the molten salt and are decomposed. Exhaust gases react with the salt eliminating the need for a downstream scrubbing system and inert gases are released through a port in the top of the vessel.

Inorganic reaction products build up in the melt and must be removed. This process is not suitable for high ash content waste such as soils because the fluidity of the melt will be adversely affected when ash content reaches 20 percent by weight. Melt is withdrawn from the melt overflow after which it is allowed to solidify before final disposal. Molten salt incinerators are not commercially available for hazardous waste applications although pilot scale units (as large as 200 pounds per hour) have been developed for coal gasification research (RMA 1992).

**A 6 4 1 4 Solar Incineration** Solar incineration uses an array of focused heliostats to concentrate the radiant energy from the sun into a reactor containing the material being processed. The very high temperatures produced result in high destruction and removal efficiencies. Removal efficiencies as high as 99.999 percent have been achieved. The process is considered innovative and the required equipment is not readily available. The amount and intensity of sunshine affect the implementability of this process.

**A 6 4 1 5 Rotary Hearth or Multiple Hearth** A rotary hearth incinerator consists of a vertical refractory lined steel shell, a rotating central shaft, a series of solid flat hearths, a series of rabble arms with teeth for each hearth, an air blower, waste feed and ash removal systems and fuel burners mounted on the walls. The waste falls from the top hearth to subsequent hearths until it reaches the bottom hearth where it is discharged as ash. Rotary hearths can also be equipped with an afterburner, liquid waste burners and side ports for tar injection. The temperature in the burning zone ranges from 1400 to 1900°F and residence times may be long compared to other incinerators.

This incinerator is best suited for hazardous sludge destruction. Solid waste often requires pretreatment such as shredding and sorting. This process can treat the same wastes as a rotary kiln provided that the solid waste is pretreated. The principal advantages of rotary hearth incineration include high residence time for sludge and low volatility materials and high fuel efficiency and ability to handle a variety of sludges, ability to evaporate large amounts of water and the ability to use a variety of fuels.

**A 6 4 1 6    Microwave Melting**    Microwave melting includes the transmission of high energy microwaves into contaminated material. The microwaves are absorbed by the contaminated material to produce a non leachable vitrified mass. This process is considered innovative and is still in the development stage. Off gas treatment and containment are required for this process. This process is considered time and energy intensive. Homogeneous wastes with a high silica content produce the most favorable final results. Non uniform melting can result leaving portions of the waste untreated.

**A 6 4 1 7    Rotary Kiln**    Rotary kiln incinerators are slightly inclined refractory lined cylinders. Rotary kiln incineration involves the controlled combustion of organic wastes under oxidizing conditions. Contaminated soils are typically fed either continuously or on a batch basis (using a waste storage hopper) into the high end of the kiln and passed through the combustion zone as the kiln rotates. Auxiliary fuel is added either to the high end (co-fired) or low end (counterfired) of the kiln. An enriched oxygen supply system is often included to enhance incineration. Rotation of the combustion chamber creates turbulence and improves the degree of burnout of the solids and wastes are substantially oxidized to gases and inert ash within this zone. Retention time can vary from several minutes to an hour or more and is controlled by feed rate, inclination and speed of rotation. Ash and slag are collected in an ash bin located at the rear of the kiln. Partial volatilization of some inorganics occurs in the primary chamber.

Off gas is directed to a secondary combustion afterburner that is a refractory lined chamber. Sufficient residence time and combustion temperature in the afterburner provide for the complete destruction of any unburned organics in the combustion gases leaving the kiln. Typical temperatures required for nearly complete destruction of a wide range of hazardous wastes range from 1800 to 2250 F in the afterburner. A liquid scrubber is used to quench effluent gases, remove particulates including volatile inorganic contaminants and neutralize any acids that may be produced. Scrubber effluent that is not recycled generally requires neutralization, clarification or other wastewater treatment prior to discharge.

Although organic solids combustion is the primary use of rotary kiln incinerators, liquid and gaseous organic wastes can also be handled by injection into either the feed end of the kiln or the secondary combustion chamber. Rotary kilns are currently most commonly used for hazardous solid waste incinerators. There are many vendors of transportable units ranging in size from 1 to 60 tons per hour throughput (Johnson, 1993). Wastes containing high quantities of caustic can result in excess slag formation which can build up and hamper kiln performance.

**A 6 4 1 8    Oxygen Enhanced Incineration**    Oxygen enhanced incineration is a thermal destruction process using an integrated combustion system that uses a new technique for mixing auxiliary fuel, oxygen, and air. Specific removal efficiencies are unknown. This incineration achieves a reduction in the toxicity and volume of the waste stream and has the ability to incinerate double the waste throughput possible with conventional incineration without an increase in carbon monoxide level emissions. Required equipment is commercially available.

The following factors may affect the applicability and effectiveness of the process

Most effective for wastes with low heating values and

Permitting and public acceptance may be difficult

**A 6 4 1 9 Liquid Injection** Liquid injection incineration includes atomizing nozzles injecting contaminated fluid into a refractory lined combustion chamber. Liquid injection can achieve destruction efficiencies greater than 99 percent, reducing the toxicity and volume of waste. Liquid injection equipment is commercially available; however, no units are currently in operation.

The following factors may limit the applicability and effectiveness of the process

Produces off gas which requires treatment

Supplemental fuel would be required

Energy intensive and

Permitting and public acceptance may be difficult

**A 6.4 1 10 High Temperature Fluid Wall** This process uses a reactor consisting of a porous carbon core surrounded by carbon electrodes that heat the core to 4000 to 5000 °F. Wastes pass through the core by gravity flow and are quickly incinerated. A nitrogen gas blanket (or fluid wall) prevents the waste from contacting the core walls. This process can achieve a removal efficiency of 84.9 percent and above. Commercial high temperature fluid wall units are available but are untested.

The following factors may limit the applicability and effectiveness of the process

Off gas from the process requires treatment

This process is considered innovative

High operation and maintenance costs may be incurred during for this process

#### **A 6 4 2 Low Temperature Thermal Desorption**

Thermal desorption is a physical separation process that is not designed to destroy organics but to volatilize (desorb) them from the waste. Typically a carrier gas or vacuum system transports volatilized water and organics to a gas treatment system. For low temperature thermal desorption, wastes are heated from 200 to 600°F (93° to 315°C) to volatilize water and

organic contaminants A carrier gas or vacuum system transports volatilized water and organics to the gas treatment system Low temperature thermal desorption systems are physical separation processes and are not designed to destroy organics The bed temperatures and residence times designed into these systems will volatilize selected contaminants but typically will not oxidize them Low temperature has been implemented to treat industrial and hazardous wastes

The following factors may limit the applicability and effectiveness of the process

There are specific feed size and materials handling requirements that can impact applicability or cost at specific sites

Dewatering may be necessary to achieve acceptable soil moisture content levels and

Highly abrasive feeds can potentially damage the processor unit

The target contaminant groups for low temperature thermal desorption systems are halogenated and nonhalogenated volatile organic compounds and petroleum hydrocarbons The technology can be used to treat halogenated and non halogenated semivolatile organic compounds and pesticides but may be less effective Excavation associated with low temperature thermal desorption poses a potential health and safety risk to site workers through skin contact and air emissions Personal protective equipment at a level commensurate with the contaminants involved is normally required during excavation operations

Approximate overall cost is less than \$100/ton (\$110/metric ton) Low temperature thermal desorption is relatively labor intensive The skill and training level required for most of the operating personnel is minimal Low temperature thermal desorption is considered to be both capital and O&M intensive

#### **A 6 4 3 HT-5 Thermal Distillation Process**

This process heats wastes in a nitrogen atmosphere to vaporize volatile and semivolatile compounds The resulting hot gases are condensed to recover liquified hydrocarbon products Some pilot and full scale testing has been performed to evaluate this process The equipment required for this process is available

The following factors may limit the applicability and effectiveness of the process

Removal efficiencies are unknown

The organic content of the waste stream

Process requires supplemental heating and cooling/refrigeration and capital costs for the purchase of nitrogen and

Process is considered innovative

#### **A 6 4 4      Pyrolysis**

Chemical decomposition is induced in organic materials by heat in the absence of oxygen. Organic materials are transformed into gaseous components and a solid residue (coke) containing fixed carbon and ash. Pyrolysis is currently under development.

The following factors may limit the applicability and effectiveness of the process:

There are specific feed size and materials handling requirements that impact applicability or cost at specific sites and

The technology requires a low soil moisture content. Highly abrasive feed can potentially damage the processor unit.

The target contaminant groups for pyrolysis are all halogenated and non halogenated semivolatile organic compounds and pesticides. The technology also may be used to treat halogenated and nonhalogenated volatile organics and fuels but may be less effective. Excavation associated with pyrolysis poses a potential health and safety risk to site workers through skin contact and air emissions. Personal protective equipment at a level commensurate with the contaminants involved normally would be required during excavation operations.

Overall cost of remediating approximately 20 000 tons (18 200 metric tons) of contaminated media is expected to exceed \$300/ton (\$330/metric ton). Pyrolysis is considered to be both capital and O&M intensive.

**APPENDIX B**

**DESCRIPTION OF GROUNDWATER TECHNOLOGIES AND PROCESS OPTIONS  
PASSING THE TECHNICAL IMPLEMENTABILITY SCREEN**

## APPENDIX B

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## **DESCRIPTION OF GROUNDWATER TECHNOLOGIES AND PROCESS OPTIONS PASSING TECHNICAL IMPLEMENTABILITY**

This section provides a description of the technologies for the remediation of contaminated groundwater at RFETS. The technologies included in this section cover the range of options and approaches available to treat contaminated groundwater or otherwise protect human health and the environment. These technologies alone or combined have been in the development of alternatives to satisfy the Corrective/Remedial Action Objectives (C/RAOs) EPA documents, engineering reference materials, technical journals, periodicals, and reference data bases were used to develop these technology descriptions.

The technologies are organized in general by (1) general response action, (2) technology type, and (3) process option. The general response actions are no action, institutional controls, containment, removal, *in situ* treatment, and *ex situ* treatment.

### **B 1 NO FURTHER ACTION**

No further action provides a baseline exposure risk scenario for comparison with the risks associated with the implementation of other technology types, and is required under CERCLA (EPA 1988). No action means no activities are conducted nor technologies implemented to address potential groundwater and surface water contamination or interrupt potential human health and environmental exposure pathways.

#### **B 1 1 Intrinsic Remediation**

Natural processes such as dilution, volatilization, biodegradation, adsorption, and chemical reactions with naturally occurring materials may reduce contaminant concentrations over time. These processes are referred to as intrinsic remediation or natural attenuation and may coincide with no action.

Occurrence of intrinsic remediation is determined by the types of contaminants present and the specifics of the site. Target contaminants for intrinsic remediation are non-halogenated volatile and semivolatile organics and petroleum hydrocarbons. Halogenated volatile and semivolatile compounds and pesticides can also be allowed to naturally attenuate but the process may be less effective and may be applicable only to some of these compounds.

The following factors may limit the applicability and effectiveness of the process:

No action and intrinsic remediation should be used only in low risk situations, and

May require periodic surface water and groundwater monitoring (EPA 1988) to determine if any changes have taken place in short term and long term risks.

## **B 1 1 1      Groundwater Monitoring**

Site specific characteristics that influence the placement of monitoring wells include the nature of the aquifer (e g artesian) characteristics of potential leachate and groundwater depth flow rates and direction of flow Based on assumptions and data about the characteristics of the site approximate permeability of soils in the zone of aeration and directions and velocities of groundwater flow the maximum probable areal extent of contaminant migration can be estimated as a basis for establishing the position of monitoring wells

Proper location and installation of monitoring wells are essential to a monitoring program A minimum of four groundwater monitoring wells are typically installed at a hazardous waste site one upgradient well and three downgradient wells However site hydrogeology is often too complex for only four wells to provide adequate detection of groundwater contamination

Upgradient wells are placed beyond the upgradient extent of contamination At least three downgradient wells are located to ensure that releases of hazardous waste or hazardous waste constituents from the hazardous waste management unit(s) to the uppermost aquifer will be quickly detected The specific number of wells to be included in a detection system depends on the horizontal spacing between well locations and the vertical sampling interval of individual wells

## **B 2                INSTITUTIONAL CONTROLS**

Institutional controls reduce exposure to site contaminants through administrative actions and access restrictions Administrative actions include land use restrictions and monitoring of conditions at the site The intent of access restrictions is to interrupt exposure pathways Access restrictions include barriers fencing and warning signs

Institutional controls may be appropriate for sites where the potential for exposure is minimal or where baseline risks are determined to be low However institutional controls may also be selected for highly contaminated sites where the risks to workers or community during remediation would exceed the present risks at the site In this case institutional controls could include site access restrictions

As indicated above institutional controls may be combined with other response actions into alternatives to satisfy remedial action objectives For example if a site is remediated through containment or treatment institutional controls such as deed restrictions or access restrictions may be implemented during as well as after the site is remediated

## **B 2 1      Access Restrictions**

Access restrictions which include fencing locks warning signs and other physical barriers reduce potential exposures by preventing or limiting access to contaminated areas Access restrictions can also include guards lighting and alarms The most common access restrictions applicable to humans would be fences around the contaminated area and locks and tags on all existing groundwater wells

The following factors may limit the applicability and effectiveness of the process

Access restrictions may need to be expanded if contaminants migrate and

Vertical access restrictions are difficult to establish

### **B 2 1 1      Fencing, Security**

Exposure to contaminants would be reduced or eliminated by installing a fence around the entire site Long term security would be provided to ensure the public does not enter into the restricted area Monitoring would need to be performed to ensure the contaminants did not migrate outside the fenced area If contamination migration occurred the fenced area may need to be expanded to ensure protection of the public

### **B 2 1 2      Lock Out/Tag Out Wells**

To limit exposure of contaminated groundwater from the public existing groundwater wells would be locked and tagged The wells would be tagged with an identification marker notifying the public that the well was contaminated The locking and tagging of groundwater wells would prevent the public from contacting the contaminated groundwater

## **B 2 2      Land Use Restrictions**

Exposure to contaminants may be reduced or eliminated through land use restrictions Land use restrictions may be incorporated in deeds or zoning requirements Often deed and zoning restrictions must be together because deed restrictions indicate what cannot be done and zoning restrictions indicate what can be done Before deed restrictions may be accomplished a comprehensive title search would need to be completed to verify Fee Simple ownership (i e mineral water and other inherent rights) of the land

### **B 2 2 1      Deed Restrictions**

Exposure to contaminants may be reduced or eliminated by adding restrictions to the property deed that limit the future land use For example residential or commercial

construction in contaminated areas could be prohibited by defining those areas and adding an appropriate stipulation in the property deed. The contaminants would not be removed but may be reduced over time by natural attenuation.

The following factors may limit the applicability and effectiveness of the process:

The mineral water or other inherent rights must be purchased if they are owned by another party, and

Potential present and future legal challenges may cause difficulties.

#### **B 2 2 2      Zoning Restrictions**

Exposure to contaminants may be reduced or eliminated by restricting future land use through zoning ordinances. Zoning restrictions would restrict development or use of the entire property rather than just the contaminated areas. Again, the contaminants would not be removed but may be reduced over time by natural attenuation.

The following factors may limit the applicability and effectiveness of the process:

Zoning restrictions may be changed by public and institutional decree at any time, and

Potential present and future legal challenges may cause difficulties.

#### **B 2 2 3      Regulatory Restrictions**

A local groundwater regulatory restriction would be obtained to require regulatory review of all groundwater well installation plans in the area. The restriction would prevent any drinking water supply wells from being installed in contaminated parts of the aquifer. This would eliminate the potential exposure pathway to the public from a contaminated drinking water supply.

### **B 3            CONTAINMENT**

Containment interrupts the exposure pathways to contaminated groundwater. Containment reduces the mobility but does not reduce the toxicity or volume of the contaminants. Containment may also prevent or reduce the infiltration/percolation of surface waters to the groundwater, thereby reducing the recharge rate of the aquifer. Containment technologies include surface water controls and horizontal, vertical, and hydraulic barriers.

### **B 3 1        Surface Water Controls**

This containment method uses soil treatment revegetation grading and compaction to create a hydraulic barrier that limits the migration of contaminated surface water Groundwater controls reduce contaminant mobility but not contaminant toxicity or volume

#### **B 3 1 1        Enhanced Soil Treatment, Revegetation, Grading, and Compaction**

The surface of the cover soils would be stabilized to decrease erosion by wind and water and to contribute to the development of a stable surface environment Vegetation is typically the aesthetically preferred final surface of a capping system Proper vegetation establishment would reduce the damaging effects from erosion due to wind and surface water runoff Plants also transmit water from the soil to the atmosphere through evapotranspiration providing a removal pathway for the water stored in the topsoil When coordinated with surrounding native species the plants also provide a pleasant blend with natural surroundings

Vegetative covers include grading and backfilling the contaminated area with general backfill/topsoil material planting vegetation and applying pea gravel

The following factors may limit the applicability and effectiveness of the process

Backfilling and grading provide no hydraulic barriers to prevent infiltration of precipitation into underlying material

Soil types and availability of water are critical for development of a vegetative surface

Periodic repair and maintenance may be required

The process is not usually a long term containment process and

Monitoring and a leak detection system may be required

### **B 3 2        Groundwater Controls**

This containment method uses extraction wells or interceptor systems to create a hydraulic barrier that limits the migration of contaminated groundwater Typically extraction wells are placed at the downgradient edge of the groundwater plume to capture the contaminated groundwater and extract it to the surface Groundwater controls reduce contaminant mobility but not contaminant toxicity or volume

### **B 3 2 1      Extraction Wells**

Movement of contaminated groundwater can be controlled or prevented by use of a specially designed hydraulic system including extraction wells. Extraction systems must have a moderate to high operational flexibility which allow the system to meet increased or decreased pumping needs. Extraction wells use pumps to raise groundwater to the surface resulting in a cone of depression that forms around each well. Usually a network of extraction wells is used. The network is designed with wells at specific depths and locations to optimize groundwater recovery. In some circumstances the need to employ directional drilling may be for extraction systems. Directional drilling includes angled boreholes where surface access may be a problem or horizontal drilling in which horizontal extraction systems are installed to capture shallow near surface groundwater. Directional drilling technologies are becoming more common in remediation systems.

### **B 3 2 2      Interceptor Trenches**

Interceptor trenches include any type of trench or buried conduit to convey liquids (unconfined groundwater) by gravity flow. French drains function essentially like an infinite line of extraction wells. To effectively collect groundwater french drains must be keyed to the bedrock. The trenches may be excavated to a depth of approximately 30 feet using conventional backhoes and to much greater depths using telescopic backhoes or clamshells. After excavation a perforated pipe is placed in the trench and backfilled with clean gravel. If surface water collection is desired the gravel will be open at the surface if not the last few feet will be filled with soil and revegetated. Collected water will drain by gravity to a pump station where it will be extracted. This process is also known as interceptor trenches and subsurface drains. Synthetic membrane cutoff walls may also be included in this category and additional information may be found in Section B 3 2 3.

The following factors may limit the applicability and effectiveness of the process

These methods are limited to depths which can be excavated

Heterogeneous aquifers low hydraulic conductivity and shallow hydraulic gradient limit applicability of this process

Design of a french drain requires prior delineation of the contaminant plume and knowledge of the aquifer properties and

Legal issues regarding water rights may need to be resolved

### **B 3 3        Vertical Barriers**

Vertical barriers prevent the migration of contaminated water by physically restricting horizontal groundwater flow. These barriers have become the principal means for containment of contaminated plumes that threaten aquifers. Used in combination with groundwater pumping or capping, these barriers must normally be attached or made contiguous (keyed) with another low permeability geological layer such as bedrock or clay in order to restrict secondary vertical migration of contaminants. The use of barriers is therefore limited to sites where such geological layers are available and accessible or where the bedrock is not heavily fractured. The major types of vertical barriers are sheet piling, slurry walls, and synthetic membrane cutoff walls.

#### **B 3 3 1        Sheet Piling**

This vertical barrier is installed by driving a sheet of corrugated metal into the ground. Additional sheets of metal can be connected to create one long solid wall around the contaminated area. By placing the metal wall around the contaminated area, it encloses the contaminated groundwater in one location and eliminates contaminant migration. The effectiveness of the sheet piling increases with time as fine-grained soil particles wash into the seams creating a better seal between sheets.

The following factors may limit the applicability and effectiveness of the process:

The technology only contains the contaminants to a specific area, and

The technology is not feasible to implement in rocky soils or large areas.

#### **B 3 3 2        Slurry Walls**

These subsurface barriers consist of a vertically excavated trench that is filled with a slurry. The slurry, usually a mixture of bentonite and water, hydraulically shores the trench to prevent collapse and forms a filter cake to reduce groundwater flow. In some cases, soil or cement is added to the bentonite slurry to form a soil bentonite or cement bentonite barrier. Slurry walls can be keyed to a confining layer of clay or bedrock or left hanging when contaminants do not mix with the groundwater. Slurry walls are often used where the waste mass is too large for practical treatment and where soluble and mobile constituents pose an imminent threat to a drinking water source. They are economical at moderate depths (40 to 70 feet) and have a low water permeability (from  $10^{-5}$  to  $10^{-4}$  cm/sec). Slurry walls have been successfully implemented at hazardous waste sites.

The following factors may limit the applicability and effectiveness of the process

The technology only contains the contaminants to a specific area

Soil bentonite backfills are not able to withstand attack by strong acids bases salt solutions and some organic chemicals There is some concern regarding the permeability of slurry walls to certain organic compounds

There is the potential for the slurry walls to degrade or deteriorate over time

The trenches are generally limited to an excavated depth of approximately 30 feet using conventional backhoes Greater depths approaching 70 feet can be achieved using telescopic backhoes or clamshells

Slurry walls are applicable to the full range of contaminants with no particular target group but are considered to be capital intensive

### **B 3 3 3 Synthetic Membrane Cutoff Wall**

Synthetic membranes are used to form a cutoff wall to divert or contain groundwater Compatibility testing of the liners with chemical wastes must be performed to determine durability In order to place a synthetic membrane liner as a vertical barrier a trench must be dug from the surface to an impervious soil layer and a drain must be placed in the bottom of the trench to remove excess water The synthetic membrane must be suspended vertically in the trench and the trench must be backfilled with sand or other suitable material To be effective the liner must be keyed into the underlying impervious barrier During construction the trench must remain open to facilitate placement of the liner Extra precautions must be taken in loose unconsolidated materials to ensure proper placement of the liner

The following factors may limit the applicability and effectiveness of the process

The technology only contains the contaminants to a specific area

Construction depending on site conditions may be difficult and the synthetic membrane may become damaged and

The trenches are generally limited to an excavated depth of approximately 30 feet using conventional backhoes Greater depths approaching 70 feet can be achieved using telescopic backhoes or clamshells

### **B 3 4        Horizontal Barriers**

Horizontal barriers are used in conjunction with vertical barriers to contain contaminated groundwater thereby reducing groundwater exposure pathways to the public. By installing a horizontal barrier surface water is diverted from the impacted area and does not infiltrate/percolate to the contaminated groundwater. By reducing the infiltration/percolation rate of surface water the recharge rate of the aquifer is reduced. Horizontal barriers applicable to surface water include asphalt based cover, compacted clay cover, and multi layer covers.

#### **B 3 4 1        Asphalt Based Cover**

An asphalt based cover involves placing an asphalt layer over a crushed stone bedding layer directly on the site surface. Before the pavement is placed the site surface must be compacted and graded to prevent differential settlement. Pavement is subject to cracking through weathering processes and has not frequently been used for long term containment of hazardous wastes.

The following factors may limit the applicability and effectiveness of the process:

- The technology only contains the contaminants in a specific area.

- Pavement is susceptible to damage by weather (e.g. sun and the freeze/thaw cycle), plants, and animals.

- Design life may be inappropriate for the contaminants of concern.

- Periodic repair and maintenance may be required.

- The process is not usually a long term containment process, and

- Monitoring and a leak detection system may be required.

#### **B 3 4 2        Compacted Clay Cover**

Compacted clay is frequently used in single or multiple layers in the final cover system of both hazardous and municipal waste landfills. These cover systems may also be utilized to contain contaminated soils. Bentonite, a natural clay with high swelling properties, is often transported to a site and mixed with onsite soil to produce a low permeability cover material. Onsite soils can sometimes be compacted to achieve the required permeability of  $1 \times 10^{-7}$  cm/sec or less. Vegetation is typically the final surface of a cover system. Proper vegetation reduces the damaging effects from erosion due to wind and surface water runoff.

The following factors may limit the applicability and effectiveness of the process

The technology only contains the contaminants in a specific area

The uniformity of compacted soil walls is difficult to control

The cover may require large volumes of construction material

Weathering (cracking) of the clay cover may require extensive maintenance and

Monitoring and a leak detection system may be required

### **B 3 4 3      Multi layer Cover**

Clay compacted soil or synthetic membranes are frequently used in single or multiple layers in the final cover system of both hazardous and municipal waste landfills. These cover systems may also be utilized to contain contaminated soils. Bentonite, a natural clay with high swelling properties, is often transported to a site and mixed with onsite soil to produce a low permeability cover material. Sometimes onsite soils can be compacted to achieve the required permeability of  $1 \times 10^{-7}$  cm/sec or less. The most common synthetic membrane materials are polyvinyl chloride, polyethylene, butyl rubber, Hypalon® and neoprene.

An example of a multi layer cover would consist of the following: (1) a gas-collection layer, (2) a composite hydraulic barrier layer combining a compacted-clay and a flexible membrane liner, (3) a biotic barrier and drainage layer, (4) a topsoil layer, and (5) a permanent vegetative cover.

The following factors may limit the applicability and effectiveness of the process

The technology only contains the contaminants in a specific area

The uniformity of compacted soil walls are difficult to control

Synthetic membrane materials can be easily damaged by weather, human activity and animals

Synthetic membrane materials can degrade over time and may need to be maintained or replaced and

Monitoring and a leak detection system may be required

## **B 4            REMOVAL**

Groundwater may need to be removed for *ex situ* treatment to lower the water table or to contain a groundwater contamination plume. Groundwater may be removed by extraction technologies such as extraction wells or interceptor trenches.

### **B 4 1            Groundwater Extraction**

Groundwater extraction is often used in conjunction with *ex situ* treatment technologies or groundwater control technologies to prevent further contamination of the groundwater. With proper placement and operation, a groundwater extraction system can capture contaminants in groundwater and control migration of contaminated groundwater. Therefore, extraction wells and interceptor trenches can serve both as a groundwater containment technology and as a collection technology.

The following factors may limit the applicability and effectiveness of the process:

Heterogeneous aquifers, low hydraulic conductivity, and shallow hydraulic gradient limit applicability of groundwater extraction.

Immiscible contaminants may not be extracted with the groundwater.

Design of a network requires prior delineation of the contaminant plume and knowledge of the aquifer properties, and

Legal issues regarding water rights may need to be resolved.

#### **B 4 1 1            Extraction Wells**

A description of extraction wells is provided in Section B 3 1 1.

#### **B 4 1 2            Interceptor Trenches**

A description of interceptor trenches is provided in Section B 3 1 2.

### **B 4 2            Groundwater Transport**

Groundwater may be transported over short distances to an onsite treatment facility with the use of truck/rail hauling or a pipeline system.

#### **B 4 2 1      Truck/Rail Hauling**

Groundwater may be transported by hauling the water in trucks or rail cars to a treatment facility

The following factors may limit the applicability and effectiveness of the process

- The distance between the contaminated site and the nearest treatment/disposal facility
- Quantity of the contaminated material
- Characteristics of the contaminated material and its compatibility with the transport system and
- Site access and topography

#### **B 4 2 2      Pipeline**

A pipeline consists of a pipeline and pump equipment used to transport groundwater. A pipeline requires removal of groundwater piping and pumps to move the groundwater to a treatment facility. Due to costs, pipeline systems are relatively short and are used as a component of treatment systems. A pipeline may be used as a temporary or long term transport system.

The following factors may limit the applicability and effectiveness of the process

- The distance between the contaminated site and the nearest treatment/disposal facility
- Quantity of the contaminated material
- Characteristics of the contaminated material and its compatibility with the transport system and
- Site access and topography

#### **B 4 3      Disposal**

Following collection, storage, or treatment, the water must be disposed. Disposal options include the onsite sewage treatment plant.

#### **B 4 3 1      RFETS Sewage Treatment Plant**

The onsite sewage treatment system is currently designed to process domestic sewage storm water and some industrial water such as compressor or steam condensate. The system may also except industrial wastes such as cleaning solutions or water in the fire lines on a case by-case basis. The system is an activated sludge treatment system which will remove organics. The system will not effectively treat metals or radionuclides. The system currently operates at an average flow rate of 70 to 140 gallons per minute (gpm) but may be operated up to 350 gpm.

The following factor may limit the applicability and effectiveness of the process:

The system will need to be evaluated to ensure that it can treat all of the OU2 COCs.

#### **B 5            *IN SITU* TREATMENT**

*In situ* treatment technologies described in the following paragraphs involve treating the contaminated groundwater in place until remedial action objectives are met. Applicability of *in situ* methods must generally be established on a site-specific basis by pilot scale treatability studies. *In situ* treatment includes biological treatment, physical/chemical treatment, and thermal treatment.

##### **B 5 1            Biological Treatment**

Bioremediation uses naturally occurring micro-organisms such as bacteria, fungi, or yeast to degrade harmful chemicals into less toxic or nontoxic compounds. Micro-organisms like all living organisms need nutrients (such as nitrogen, phosphate, and trace metals), carbon, and energy to survive. Micro-organisms break down a wide variety of organic (carbon containing) compounds found in nature to obtain energy for their growth. Many species of soil bacteria, for example, use petroleum hydrocarbons as a food and energy source, transforming them into harmless substances consisting mainly of carbon dioxide, water, and fatty acids. Bioremediation harnesses this natural process by promoting the growth of micro-organisms that can degrade contaminants and converting them to nontoxic byproducts. The major biological processes include enhanced anaerobic bioremediation and co-metabolic process.

##### **B 5 1 1        Enhanced Anaerobic Bioremediation**

The activity of naturally occurring microbes is stimulated by circulating water based solutions through contaminated groundwater to enhance *in situ* biological degradation of organic contaminants. Nutrients, methane, or other amendments may be used to enhance bioremediation and contaminant desorption from subsurface materials. Generally, the process includes above

ground treatment and conditioning of the infiltration water with nutrients and methane (or other electron acceptor) source. Bioremediation has been successfully applied at hazardous waste sites.

The following factors may limit the applicability and effectiveness of the process:

Extensive treatability studies and site characterization may be necessary.

Preferential flow paths may severely decrease contact between injected fluids and contaminants throughout the contaminated zones.

The system should be used only where groundwater is near the surface.

Bioremediation may not be applicable at sites where there are high concentrations of heavy metals, highly chlorinated organics, or inorganic salts.

Target contaminants for *in situ* bioremediation are non halogenated volatile and semivolatile organics and petroleum hydrocarbons. Halogenated volatile and semivolatile organics and pesticides also can be treated, but the process may be less effective and may only be applicable to some of these compounds. Methane-oxidizing processes may be effective in enhancing degradation of volatile halogenated compounds.

Anaerobic bioremediation has not been demonstrated for *in situ* applications because of the difficulty in maintaining an oxygen free environment and because of the temperature sensitivity of the microbes. Research is currently being conducted to investigate the feasibility of anaerobic degradation for aquifers.

## **B 5 1 2 Co-Metabolic Processes**

Water containing dissolved methane and oxygen is injected into groundwater to enhance methanotrophic biological degradation. This class of micro-organisms can degrade chlorinated solvents such as vinyl chloride and TCE by co-metabolism. Co-metabolism is one form of secondary substrate transformation in which enzymes produced for primary substrate oxidation are capable of degrading the secondary substrate fortuitously, even though the secondary substrates do not afford sufficient energy to sustain the microbial population. Development of co-metabolic processes is at the pilot scale.

While development of bioreactors for methanotrophic TCE biodegradation is progressing well, *in situ* application has not yet been demonstrated at a practical scale. A field demonstration project has been conducted at DOD's Moffett Naval Air Station and another is being conducted at DOE's Savannah River Site.

The following factors may limit the applicability and effectiveness of the process

This technology is still under development and

Where the subsurface is heterogeneous it is very difficult to circulate the methane solution throughout every portion of the contaminated zone Higher permeability zones are cleaned up much faster because groundwater flow rates are greater

Contaminants treated by the co-metabolic processes are halogenated volatile and semivolatile organics Non halogenated organics petroleum hydrocarbons and pesticides also can be treated but the process may be less effective and only applicable to some compounds

The overall cost for this technology should be in the range of \$3 00-\$10 00/1000 gallons (\$0 79 \$2 64/1000 liters)

O&M costs can be significant because a continuous source of methane solution must be delivered to the contaminated groundwater

## **B 5 2 Chemical/Physical Treatments**

Physical treatment is a process in which the hazardous waste is separated from its carrier by various physical methods such as adsorption distillation and filtration Physical treatment is applicable to a wide variety of wastes but further treatment is usually required For this reason physical treatment is often discussed along with chemical treatment

Chemical treatment is a process in which the hazardous waste is altered by a chemical reaction in order to destroy the hazardous component Wastes that can be treated by this method include both organic and inorganic compounds without heavy metals Drawbacks to this method include the inhibition of the treatment process reaction by impurities in the waste and the potential generation of hazardous byproducts

The major *in situ* physical/chemical technologies include air stripping directional wells dual phase extraction free product recovery hydrofracturing oxidation and vacuum vapor extraction Directional wells and hydrofracturing enhancement technologies that are often used in conjunction with *in situ* physical/chemical treatment are also discussed in this section

### **B 5 2 1 Air Sparging**

Air is injected into a saturated matrices creating an underground stripper that removes contaminants through volatilization The technology is designed to operate at high air flow rates in order to effect volatilization (as opposed to the lower air flow rates used to increase groundwater oxygen concentrations to stimulate biodegradation) Air stripping must operate in

tandem with SVE systems that capture volatile contaminants stripped from the saturated zone  
Air stripping has been successfully implemented at hazardous waste sites

The following factors may limit the applicability and effectiveness of the process

Depth of contaminants and specific site geology must be

Pressure levels must be designed for site specific conditions

Channeling of the air flow can occur and

Using air stripping without SVE could create a net positive subsurface pressure that could induce contaminant migration beyond the contaminated zone

Target contaminants for air stripping are halogenated and non halogenated volatile organic compounds and petroleum hydrocarbons Only limited information is available on the process

The overall costs should be less than \$3 00/1000 gallons (\$0 79/1000 liters) Air stripping is considered to be neither capital nor O&M intensive

#### **B 5 2 2      Passive Treatment Walls**

A permeable reaction wall is installed in a excavated trench across the flow path of a contaminant plume allowing the plume to passively move through the wall Target contaminants for passive treatment walls are halogenated volatile and semivolatile organic compounds and inorganics The technology can be used but may be less effective in treating some non halogenated volatile and semivolatile organics and petroleum hydrocarbons The halogenated compounds are degraded by reactions with a mixture of porous media and a metal catalyst Development of passive treatment walls is at the pilot scale

The following factors may limit the applicability and effectiveness of the process

The technology is applicable only in relatively shallow aquifers because the trench must be constructed down to the level of the bedrock or an impermeable clay and

Passive treatment walls are often only effective for a short time because they lose their reactive capacity requiring replacement of the reactive medium

There is inadequate information to determine overall cost for this technology Passive treatment walls are considered to be capital intensive

### **B 5 3 Thermal**

Thermal treatment processes may decompose hazardous components in groundwater into less hazardous or non hazardous components. When subjected to high temperatures, organic wastes decompose to similar, less toxic forms. Complete combustion yields carbon dioxide and water plus small amounts of carbon monoxide, nitrous oxides, and chlorine and bromine acid gases. Thermal treatment is most suitable for organic wastes and is less effective when attempting to detoxify heavy metals and inorganic compounds. One drawback of thermal treatment is the high cost involved.

#### **B 5 3 1 Thermally Enhanced Soil Vapor Extraction**

Thermally enhanced SVE uses steam/hot air injection or electric/radio frequency heating to increase the mobility of volatiles to facilitate extraction. The process includes a system for handling off gases. Thermally enhanced SVE may be used to treat the soils in the saturated zone. Thermally enhanced SVE has been applied to contaminated soils at hazardous waste sites and is designed to treat halogenated and non halogenated semivolatile organic compounds. Thermally enhanced SVE technologies are also effective in treating some pesticides, depending on the temperatures achieved by the system. The technology may also be used to treat some halogenated and non halogenated volatile organic compounds and petroleum hydrocarbons, but effectiveness may be limited.

The following factors may limit the applicability and effectiveness of the process:

- Debris or other large objects buried in the media can cause operating difficulties.

- Use of the technology is limited to a slope of 5° or less.

- Performance varies depending upon the process selected because of the maximum temperature achieved, and

- The soil structure at the site may be modified depending upon the process selected.

The thermally enhanced SVE processes used by each vendor are notably different and should be investigated individually for more detailed information. Heating mechanisms employed by vendors may include, but are not limited to, radio frequency heating (Section B 4 4 2) and 6-phase heating. A 6-phase heating demonstration project is underway at RFETS; results will be available under separate cover. Since thermally enhanced SVE is an *in situ* remedy and all contaminants are under a vacuum during operation, the possibility of contaminant release is minimal.

Available data indicate that the overall cost for treatment using thermally enhanced SVE systems is approximately \$50-\$75/ton (\$55 \$82/metric ton) excluding treatment of off gases and groundwater. Thermally enhanced SVE is considered to be both capital and O&M intensive.

## **B 6            *EX SITU* TREATMENTS**

For the *ex situ* treatment of groundwater, the groundwater would be extracted from the ground, treated in the existing onsite groundwater treatment facility, and released. The following subsections describe chemical/physical treatment and the onsite water treatment system.

### **B 6 1            Chemical/Physical**

Physical treatment is a process in which the hazardous waste is separated from its carrier by various physical methods such as adsorption, distillation, and filtration. Physical treatment is applicable to a wide variety of wastes, but further treatment is usually required. For this reason, physical treatment is often discussed along with chemical treatment.

Chemical treatment is a process in which the hazardous waste is altered by a chemical reaction in order to destroy the hazardous component. Wastes that can be treated by this method include both organic and inorganic compounds. Drawbacks to this method include the inhibition of the treatment process reaction by impurities in the waste and the potential generation of hazardous byproducts.

#### **B 6 1 1            Onsite Water Treatment Plant**

The onsite water treatment system is currently designed to process groundwater contaminated with organic and inorganic contaminants (including radionuclides). The system was specifically designed in 1989 to remove organics, uranium, and heavy metals. The treatment system consists of an influent storage and transfer system, separate treatment systems for organic and inorganic contaminants, and an effluent storage and discharge system. The first treatment system is designed to oxidize organics through an ultraviolet/hydrogen peroxide (UV/H<sub>2</sub>O<sub>2</sub>) treatment unit. The second treatment system consists of an ion exchange system that removes uranium, heavy metals, selected anions, and hardness. The system is designed for an average flow rate capacity of 30 gallons per minute (gpm) and currently operates for a normal 8 hour operating shift.

The following factors may limit the applicability and effectiveness of the process:

The system will need to be evaluated to ensure that it can treat all of the OU2 COCs.

The capacity of the system may not be adequate to handle all of the OU2 groundwater and additional site waters

# **NOTICE:**

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**Technical Memorandum No 2  
Initial Screening of  
Remedial Technologies and Identification  
Of Remedial Alternatives for  
Operable Unit No 2**

**U S Department of Energy  
Rocky Flats Environmental  
Technology Site  
Golden, Colorado**

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